FACTORS AFFECTING THE MOVEMENT OF POTASSIUM IN MINERAL SOILS

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INTRODUCTION

The mineral soils of Florida are generally coarse textured and classified as sands, loamy sands, or sandy loams. These soils are mostly derived from marine deposits and have been weathered under semi-tropical conditions. The relatively high annual rainfall and temperatures have resulted in extensive leaching of bases and colloidal materials from the surface soil. The soils are inherently low in potassium bearing minerals and the total potassium content usually ranges from 300 to 800 pounds per acre in the surface six inches of soil, except in the fine-textured soils of western Florida (26). Of the total potassium present, about 90 percent is non-exchangeable and not immediately available for plant use. The remaining 10 percent is not sufficient in most instances for economic production of crops without the addition of fertilizer potassium.

Potassium fertilizers, therefore, are used extensively in the production of all the principal crops of the State. The amounts applied annually range from 50 to 100 pounds of K_2O per acre for most pastures and field crops up to amounts of 200 to 400 pounds for many vegetables and fruit crops. The annual consumption of fertilizer potassium in Florida was estimated to be more than 120,000 tons of K_2O in 1958-1959, according to reports of the Florida State Department of Agriculture. Since the cost of this plant nutrient was in excess of $12,000,000, soil management practice which can be developed for the conservation or more efficient utilization of potassium may result in large savings to farmers.

Although potassium fertilizers are generally applied to Florida soils in greater quantities than actually removed in the harvested crop, accumulation of potassium in cultivated soils is rarely reported. In fact, the low base exchange capacity of Florida's sandy soils, in conjunction with the high annual rainfall, provide conditions favorable for leaching of applied potassium salts. The extent of this leaching has been variously reported from quite severe in the case of heavily fertilized citrus and vegetable crops to almost nil with pasture and field crops. A number of factors, such as rates and placement of fertilizers, ion balance in the fertilizer zone, soil cover, amount and intensity of rainfall, and soil reaction have doubtless resulted in differences in potassium movement which have been reported in various studies. It is the purpose of this investigation to more fully relate these factors to potassium movement in mineral soils. Purpose

LITERATURE REVIEW

Potassium fixation and movement in soils have been studied quite extensively. Numerous investigators have shown that added potassium is fixed into a difficultly available form in many soils (18, 37, 48, 49, 66, 72, 74, 75). Potassium fixation has usually been associated with fine textured soils containing montmorillonitic and illitic type clay minerals. Volk (66) noted that kaolinitic type clays did not fix added potassium.

Leaching of potassium, however, has been reported to be a major problem in many sandy soils (52). Factors which influence the leaching of potassium from soil will be reviewed in the following order: (a) soil physical properties, (b) soil reaction and liming, (c) associated anions and cations, (d) rates of fertilizer application, (e) intensity of rainfall, and (f) soil cover.

Soil Physical Properties

Volk (67) measured the leaching of applied fertilizer potassium from a fine sandy loam, a very fine sandy loam, and a clay loam during eight years in which annual applications of potassium salts equivalent to 10, 20, 40, and 80 pounds of K_2O per acre were made. The two coarser textured soils lost about three to four times as much of the applied potassium from the surface 8 inches as did the clay loam. The potassium losses at the highest rate of application for the three soils were 34, 31, and 9 percent, respectively.

Spencer studied the retention and availability of cations in several sandy soils of Florida and found that soils differ considerably in their ability to retain the same cation. He compared his values with those of other investigators and concluded that hydrogen ions are held more strongly on sandy soils than on soils with high clay content. Jamison (32) pointed out that potassium was retained very weakly in some sandy soils of Central Florida and that none was fixed in non-available forms.

To a celery field on Leon sand where total applications equivalent to 800 pounds of K_2O per acre were applied in February and March, Blue et al. (10) found that most of the potassium had leached from the top 30 inches of the soil by late August. They also reported no appreciable accumulation of potassium in the top 30 inches in fields that had been heavily fertilized for celery production for forty years.

Peech (53) noted a direct relationship between the organic matter content and base exchange capacity and the retention of potassium in soils in Florida citrus groves. He found that the exchange capacity increased approximately 2.0 milliequivalents per unit increase in the percent organic matter in the soil. Collison (14) stated that the retention of potassium applied to virgin sandy Florida soils was significant for the first few years after the soils were brought under cultivation but decreased thereafter. The ability of these soils to retain potassium decreased due to the loss of organic matter following cultivation.

By means of K^{42}, Henderson and Jones (29) traced the movement of potassium from KCl when applied to the surface of a silt loam soil at rates of 600 pounds per acre. With an infiltration of 2 1/2 inches of water, only 5 percent of the potassium from the KCl penetrated beyond 1 5/8 inches of soil, and the limit reached was about 3 1/2 inches. Stauffer and Rust (62) observed that leaching losses from soils are generally, but not always, found to correlate with the amount of percolate in studies in Illinois. Leaching losses, especially potassium, were quite low in eight silt loam soils used in this study. Jones (33) observed that a clay soil retained twice as much exchangeable potassium as did humic acid. Exchangeable potassium in a peat was extracted four times more readily with water and carbonated water than that in a sample of silt loam soil, practically free of organic matter. Benjaminsen (7) found that noticeable leaching of added potassium had occurred from a sandy loam soil after a period of several months, whereas no movement had taken place in a heavy clay soil. Other workers (9, 19) have reported little potassium lost by leaching from fine-textured soils.

Soil Reaction and Liming

Peech (52) emphasized the importance of pH control on base retention in Norfolk sands. He stated that two of the important factors that govern the availability and utilization of ions in light sandy soils are leaching and fixation, which in turn are controlled in part by soil reaction.

Pearson (51) stated that liming acid soils reduced leaching losses of potassium because "the H and Al ions in the strongly acid clay have higher energy of replacement than K ions. They, therefore, force more of the K ions into the soil solution where they are susceptible to leaching. After liming, much of the H and Al ions are eventually replaced by Ca ions, which is a weaker competitor, and K ions are able to occupy a larger share of the exchange position."

Thomas and Coleman (63) suggested that the cation-binding sites of soils are of three types as follows:

1. Permanent charges, probably resulting from isomorphous substitution. These charges are usually neutralized by Ca in well limed soils and by Al in acid soils.

2. pH dependent charges caused by dissociation of weakly acidic groups on clay surfaces, by selective absorption of OH, or by changes in coordination of metal ions in clay crystals. At high pH's these sites are countered by metal cations, but at lower pH's they do not exist or are covalently bonded with hydrogen.

3. Charges due to organic matter, also weakly acidic in nature, but distinguished from the weakly acidic clay charge by their relatively greater affinity for polyvalent cations as compared to monovalent cations.

They concluded that the effective exchange capacity of a soil is the sum of several components, and may be changed by treatments. They found that calcium-saturated soils retained more potassium than aluminum-saturated soils in four soils representing extremes in texture and cation-exchange characteristics. The change from aluminum to calcium-saturated was accompanied by an increase in cation exchange capacity in all the soils. Therefore, the increase in exchange capacity after liming an acid soil, as well as the replacement of aluminum by calcium on the exchange complex, would account for greater potassium retention from calcium-saturated over aluminum-saturated soils.

Most research workers agree with the principle that liming acid soils should increase the retention of added potassium. However, several workers have questioned the practical significance of liming on retention of potassium in very sandy soils. Jamison (32) found that potassium was retained so weakly in several Florida soils as to make pH of little practical consequence. He stated that the total potassium found in these light sandy soils of Florida was about the same as the sum of the soluble and exchangeable forms. Potassium accumulated temporarily from applications only when there were droughty periods and leached out when the rains came. The fact that potassium is so weakly adsorbed in light sandy soils and cannot compete with other ions added in the fertilizer and spray materials would account for its high leachability from sandy citrus soils under all pH conditions (61). Peech (52) concluded that potassium applied in the form of neutral salts was subject to rapid leaching in light sandy soils regardless of soil reaction. Other workers (23, 35) have made the same general observations on the behavior of potassium and potassium fertilizers in Florida soils.

A number of workers have demonstrated that liming acid soils improves the retention of added potassium on sandy soils (57, 25, 39).

Volk and Bell (69) showed that pH is significant in the retention of potassium in Norfolk loamy sand but that soil reaction becomes much less critical in soils of higher exchange capacity. Harper (28) made the same observations when studying the effect of soil reaction on the availability of plant nutrients. Strongly acid sands were usually deficient in available potassium but the clay content was more important than degree of acidity in determining the quantity of replaceable potassium in medium and fine-textured soils. Mehlich (45), however, did not agree completely with these results and concluded that acid subsoils, despite high clay content, do not retain nutrients and should be limed.

Peech and Bradfield (54) discussed the effect of lime and magnesium on soil potassium under various conditions. An increase in the degree of calcium saturated will favor the adsorption of potassium from its neutral salts, whereas an increase in calcium-ion concentration will effect the liberation of adsorbed potassium. The influence of magnesium is similar to calcium except that the adsorption of potassium is reduced considerably more in the presence of excessive magnesium. In the absence of neutral salts, the soluble potassium will increase upon liming, because in salt-free systems the clay hydrolyzes, especially at high base saturation.

York and Rogers (76) noted that the ultimate beneficial effect of liming on the potassium status of soils with low potassium reserves may be reduced by the rapid depletion of soluble potassium by plants, erosion, and leaching.

Associated Anions and Cations

Jacobson et al. (31) found that calcium and potassium were removed in greatest amounts from the soil receiving a KCl treatment, followed by K_2SO_4, K_3PO_4, and K_2CO_3 treatments. Gammon (22) reported the relative rates of leaching of potassium from KCl, K_2SO_4, and K_2CO_3 in laboratory studies. Most of the applied potassium was retained by the soil from K_2CO_3 and although both were low, slightly more was retained when KCl was used than with K_2SO_4. The leaching of chloride and sulfate ions through columns of whole soil and soil clay was investigated by Berg and Thomas (8). On a sandy loam subsoil, essentially all the chloride applied was recovered in 90 ml. of leachate, whereas, considerably more sulfate was retained. They concluded that chlorine, although absorbed, will desorb readily at pH values found under field conditions. A number of other workers have reported the same general pattern of leaching of chlorides, sulfates, and nitrates from various soils (36, 40, 71).

Ayres and Hagihara (4) studied the adsorption of potassium from KCl, K_2SO_4, K_3PO_4, and KH_2PO_4 by Hawaiian soils of the humid region. The capacity of these soils to retain potassium was very slight from KCl, considerable from K_2SO_4, and marked from various phosphates of potassium. Substantial percolation losses of potassium from KCl occurred before there was any loss from either K_2SO_4 or K_3PO_4; and from K_2SO_4 before any of the potassium from K_3PO_4 was leached from the soil. Losses of potassium from KCl were smaller when applied to the soil with Ammophos or ammonium sulfate than when used alone. Damaty and Axley (16), however, reported that greater quantities of exchangeable potassium were retained in soils that had been treated with monopotassium phosphate than in those treated with similar quantities of KCl or KCl and monocalcium phosphate. Where large quantities of KPO_3 and K_2SO_4 were added in single applications to a soil, almost twice as much potassium was leached from KPO_3 than as from K_2SO_4 (42). Since losses of calcium and magnesium in leachings were diminished substantially following KPO_3 additions in this test, this may account for more potassium being leached from this treatment. This was pointed out by Volk and Bell (70) who showed that the nature of the cation-anion balance is of major importance in determining the kind and amount of salts appearing in the leachate. They found some indication that the movement of potassium was decreased where large concentrations of calcium salts were present in the leachate. Morgan (46), also reported evidence of a reciprocal relationship in the release of soluble forms between calcium and potassium.

Andrews (2) reviewed the effects of lime and fertilizer constituents on the leaching of potassium. Lime when mixed with the mass of soil conserves potassium from leaching, but calcium from band-applied fertilizers does not have this effect. When fertilizers contain large quantities of sulfates, dolomitic lime should conserve the potassium supply more than calcic lime, because of the high solubility of $MgSO_4$ and the subsequent leaching of sulfate as $MgSO_4$ instead of K_2SO_4. The action of sulfur in band-applied fertilizer depletes the fertilizer potassium rapidly. Unused nitrogen of fertilizers tends to increase the leaching of both potassium and calcium. Extensive investigations, especially in lysimeters (41, 43, 44), corroborated these conclusions on the effect of lime and calcium salts on the leaching of potassium. Ririe *et al*. (56) also reported increased leaching of potassium from a soil where $CaSO_4$ was applied.

Unused nitrogen of fertilizers tends to increase the leaching of both potassium and calcium. Tidmore and Williamson (64) reported that sodium nitrate had no effect on exchangeable potassium in Norfolk sandy loam, although ammonium sulfate and urea decreased the exchangeable potassium by approximately 50 percent more than in plots receiving no nitrogen. Barnette and Hester (5) found a decrease in exchangeable bases, in Norfolk sand, proportional to the amount of sulfate of ammonia applied up to 5,000 pounds per year. Other workers (13, 15, 47) have pointed out the adverse effect of ammonium sulfate on the leaching of potassium, calcium, and magnesium. Pearson (50), however, stated that there were no appreciable differences in the effects of urea, sodium nitrate, and ammonium sulfate on the leaching of potassium, provided these materials were rendered physiologically neutral. Downward movement of potassium was reduced by 50 percent on ammonium sulfate plots where the equivalent acidity of ammonium sulfate was neutralized by lime.

The leaching loss of potassium was negligible from grass plots treated with heavy applications of urea and ammonium nitrate (68).

An accumulation of potassium in the surface 2 inches of soil took place, but actual reduction of soil potassium was apparent at greater depths. Barrows and Drosdoff (6) noted that potassium saturation of the soil was highest at all depths when sodium nitrate was used in tung fertilization and lowest when ammonium nitrate was the source of nitrogen.

DeMent and Stanford (17) showed that particle size and water solubility of several potassium materials affect their susceptibility to leaching. Leaching the soil-fertilizer system immediately after potassium application removed potassium from KPO_3 in relation to its potassium water solubility. More potassium was leached from -35 mesh than from -6+19 mesh size on the very low water soluble compounds. However, the reverse was true for completely soluble materials as more potassium was leached from larger particle size of both potassium chloride and potassium phosphates than from finely ground material. It was found that finely ground potassium calcium pyrophosphate moved downward very little during an eight-month period in Eustis loamy fine sand under field conditions (39).

Rates of Fertilizer Application

In a study of the percentage base saturation of Lakeland sand under tung trees, Barrows and Drosdoff (6) reported that potassium saturation was increased at all depths by high potassium fertilization. Lutrick (39) noted the relationship between rates of potassium and amounts leached from limed and unlimed plots on Eustis loamy fine sand. He concluded that annual applications of potassium salts equivalent to 50 to 100 pounds of K_2O per acre would not leach beyond the root zone of most field crops on this soil. Gammon and Blue (24) suggested that potassium should be applied to pastures in several small applications during the year rather than in a single large application. When a single application is made, much of the potassium may be lost in luxury consumption or leached.

MacIntire et al. (41) reported that the larger the addition of potassium at one application, the greater was the total loss of potassium. About 80 percent of an initial application of 800 pounds of K_2O per acre from KCl, KNO_3, and K_2SO_4 was leached from the soil during a 10-year lysimeter study.

Pratt and Goulben (55) found no increase in exchangeable potassium of a clay loam soil at the 24 to 36 inch depth until the rate of application of potassium salts exceeded 400 pounds of K_2O per acre.

Volk and Bell (70) compared band placement to broadcast application of fertilizer on the leaching of nutrients from both cropped and fallow soils. The leaching losses of calcium and potassium from the cropped lysimeter were highest from the broadcast application. In fallow lysimeters, potassium loss was higher from the band placement.

Intensity of Rainfall

Kime (35) found that considerable potassium was retained from KCl after 8 inches of water had been applied to a sandy soil, while large amounts of calcium and magnesium were leached from the same soil. Sixty percent of the total potassium present in the soil immediately following the application of a mixed fertilizer was leached with 16 inches of water. In field studies, about 30 to 50 percent of the total potassium was lost during the first 8 to 10 inches of rain, while after 20 inches of rainfall about 75 percent had leached. Allison et al. (1) reported that 23 percent of the potassium leached from lysimeters during a 7-year study was collected during a 6-month period of especially heavy rainfall. This relationship between the intensity of rainfall and leaching of potassium from soils has been pointed out by several other workers (3, 4, 20, 24, 34).

In a 4-year study of nutrient losses by erosion, Rogers (58) found that the soil's supply of exchangeable potassium was depleted by sheet erosion at a much greater rate than the more difficultly soluble fraction. He noted a somewhat higher concentration of ions in the runoff water at the beginning of the runoff period than at the peak. He concluded the amounts of potassium lost through erosion were too large to be accounted for by exchangeable potassium and, therefore, must have come from applied soluble salts.

Soil Cover

Truog and Jones (65) reported that plants growing on the soil is an important means of retaining potassium in sandy soils. A turnip crop affected a 50 to 90 percent reduction in leaching losses of ions from Norfolk fine sand (70). Potassium losses during 3 months of study were less than 1 percent of the amount applied. Allison et al. (1) noted that potassium was lost readily from Lakeland sand in lysimeters in the absence of a crop. Various cropping practices, however, reduced the leaching losses up to 80 percent. The beneficial effect of winter legumes in preventing potassium from leaching below 8 inches was reported by Volk (67) during a study covering an eight-year period. He found that without legumes 9 to 32 percent of the applied potassium was leached, and with legumes only 0 to 6 percent was leached. The average savings amounted to 17 percent of the total potassium applied.

Gow (27) conducted experiments on Hawaiian soils and concluded that the retention of potassium applied to an acid soil, which had a long history of $(NH_4)_2SO_4$ additions, was unsatisfactory in the absence of vegetation, but was much better when sugar cane was grown. However, under these conditions, applications of potassium in excess of crop requirement would not be expected to increase the exchangeable potassium content.

The pattern of vertical distribution of exchangeable potassium can be severely modified by the growth of plants. Lilleland (38) determined the exchangeable potassium contents of soil samples taken at 1-foot intervals in 21 prune orchards. In all cases, the potassium content decreased with depth due to the extraction of potassium by the trees from a large volume of soil and a subsequent return to the soil surface by leaf-drop.

Wander and Gourley (73), in studies with apple orchard soils, observed no appreciable movement of potassium below 6 inches from sod or cover crops. Under a straw mulch, however, replaceable potassium was very high to a depth of 24 to 32 inches although no potassium, apart from that in the straw, had been applied. Pratt and Goulben (55) noted that manure exhibited the same effect on the movement of exchangeable potassium in soils. This was explained on the principle that the manure increased the water infiltration rate of the soil, thereby allowing potassium to move more readily.

EXPERIMENTAL PROCEDURES

A number of factors affecting the movement of potassium were studied in outside lysimeters, in the greenhouse, and in the laboratory. The experimental procedures followed in these investigations are described in the order: lysimeter, greenhouse, and laboratory experiments.

Lysimeter Experiments

Lysimeter experiments were conducted with both summer and winter crops. These studies were carried out in 12 lysimeters that were 48 inches in depth and approximately 63 inches in diameter with an area of 1/2000 of an acre. They were constructed of sheet iron, painted with black asphaltum and buried almost to ground level with sufficient projection to prevent surface runoff. These tanks were cylindrical in shape with a conical bottom. Each tank had an outlet tube leading to the interior of the collecting chamber.

The lysimeters were filled by profile to a depth of 4 feet with Arredondo fine sand. The soils from each lysimeter were analyzed prior to starting the present study to determine any residual differences resulting from previous management. The results are given in the first sampling date of Table 32 (Appendix).

The fertilizer treatments and cropping practices followed for winter and summer crops are given in Table 1.

Table 1--Fertilizer treatments and cropping practices used in lysimeters.

Lysimeter No.	Lbs/acre K_2O	Method of application	Winter crops	Summer crops
1	60	Band	Cabbage	Sweet potatoes
7	60	Broadcast	Cabbage	Sweet potatoes
8	60	Broadcast	Oats	Millet
9	60	Broadcast	Fallow	Fallow
11	120	Band	Cabbage	Sweet potatoes
3	120	Broadcast	Cabbage	Sweet potatoes
10	120	Broadcast	Oats	Millet
5	120	Broadcast	Fallow	Fallow
2	240	Band	Cabbage	Sweet potatoes
12	240	Broadcast	Cabbage	Sweet potatoes
6	240	Broadcast	Oats	Millet
4	240	Broadcast	Fallow	Fallow

All lysimeters were saturated with tap water and allowed to drain free of gravitational water just prior to the first treatments. Phosphorus, from concentrated superphosphate (47 percent P_2O_5), was applied to all plots at a rate of 120 pounds of P_2O_5 per acre. A total of 180 pounds per acre of nitrogen (N), from ammonium nitrate, was added to all lysimeters. One hundred twenty pounds per acre of N was applied in the initial fertilizer and the remaining 60 pounds was applied in two topdressing applications of 30 pounds per acre, respectively. The phosphorus, KCl, and the initial rate of NH_4NO_3 were applied as a mixed fertilizer at planting.

The treatments for the first phase of study were applied November 11, 1958, and all lysimeters except those to be kept fallow were planted to cabbage or oats on that date. Cabbage was planted in a ring about a foot within the edge of the lysimeter and thinned to 15 plants per lysimeter. Oats were broadcast at the rate of 3 bushels per acre. For broadcast treatments, fertilizer was applied uniformly and incorporated in the surface 3 inches of soil. Fertilizer, for band treatments, was applied in double bands 8 inches apart and 3 inches deep on each side of the cabbage row.

Leachings were collected continuously in 20-gallon cans during the period of the experiments. Each collection was limited to a maximum of 1 to 1 1/4 acre-inch equivalent. The quantity of leachings was measured and aliquots taken and analyzed immediately for nitrate nitrogen for each consecutive collection between November 11, 1958 and September 30, 1959. The aliquots were later analyzed for calcium, magnesium, potassium, and chlorine content.

Cabbage and oats were harvested on April 11, 1959 by cutting the plants at ground level. Oven-dry plant yields were recorded and plant samples taken for calcium, magnesium, and potassium determination.

After the first crops were harvested, the lysimeters remained undisturbed and the collection of leachings continued until May 7, 1959. The surface soil in each lysimeter was then treated with a broadcast application of $Ca(OH)_2$, that was mixed with the top 3 inches of the soil in amounts to adjust the pH of the surface soil to approximately 6.0.

On May 11, the fertilizer treatments were reapplied to the same lysimeters. Ten sweet potato plants were transplanted in lysimeters 1, 2, 3, 7, 11, and 12, and pearl millet was seeded broadcast in lysimeters 6, 8, and 10, and thinned to 55 plants per lysimeter. The millet was cut on July 10, and again on September 7. Sweet potato vines and roots were harvested September 7. The vines were cut even with the soil surface and the marketable roots were dug. Oven-dry weights were recorded and aliquots of plant materials were taken for calcium, magnesium, and potassium determinations.

Soil samples from each lysimeter were taken at depths of 0 to 12 and 12 to 24 inches before the initial treatments were applied, at the end of the winter crops and after the last crops were harvested. Each sample was a composite of five cores. Cation exchange capacity, exchangeable calcium, magnesium, potassium, and soil pH were determined for each sample.

Greenhouse Experiments

Since procedures for conducting the several greenhouse experiments were very similar, they will be discussed together in one section. For the individual experiment, only those procedures which are not common for all experiments will be discussed.

Three-gallon glazed earthenware pots, fitted with drainage outlets at the bottom, were used in these experiments. The soils used in the investigations, Lakeland fine sand and Arredondo fine sand, were air dried, screened through a one-fourth inch sieve, and 13,500 grams of soil weighed directly into the pots. Analyses of the soils used in the experiments are given in Table 2.

In preliminary studies, the amount of water required to saturate each soil was determined. The results were used in calculating the amount of water needed to insure complete leaching of the soil. Since Lakeland soil retained 3,500 ml and the Arredondo soil held

3,800 ml of water against gravitational movement, a minimum of these volumes of leachates was collected for each leaching period. Furthermore, deionized water was added in quantities sufficient to remove as nearly as possible equal amounts of leachate from each pot.

Table 2--Analyses of soils used in greenhouse experiments.

Soil	pH	Cation exchange capacity (me./100 g.)	Exchangeable bases (me./100 g.)		
			Ca	Mg	K
Lakeland	5.2	2.90	0.82	0.26	0.02
Arredondo	5.3	3.60	0.55	0.23	0.03

The pots were watered as needed for good plant growth before the leaching treatments were applied. For experiments 1 and 2, the pots were leached three times with aliquots taken to each leaching period for Ca, Mg, K, NO_3, Cl, and SO_4 analysis.

Oven-dry weight of all plant forage was recorded and samples taken for chemical analysis at each harvest. Each plant sample was analyzed for Ca, Mg, and K content.

Ammonium nitrate was added uniformly to all pots before the crops were planted and after each leaching period to prevent nitrogen deficiency from limiting plant growth. A total of 600 pounds of NH_4NO_3 per acre was applied during each of the first two experiments and 400 pounds of NH_4NO_3 per acre for the third experiment.

Concentrated superphosphate was added to all pots in amounts to give equal phosphate applications to all pots. All fertilizer materials were added in the solid form and mixed with the top 4 inches of the soil, except for nitrogen, which was applied in solution.

Experiment 1. Associated anions of potassium fertilizers

Lakeland fine sand was placed in three-gallon pots in the greenhouse. Lime, as $Ca(OH)_2$, was mixed with the entire soil at a rate equivalent to 1,000 pounds of $CaCO_3$ per acre before planting. Seven sources of potassium fertilizers were applied at a rate equivalent to 200 pounds of K_2O per acre. All materials were added on a surface area basis. The materials included in the study were: KCl, KNO_3, K_2SO_4, K_2CO_3, KH_2PO_4, KPO_3 (13.7 percent water soluble), KPO_3 (99.7 percent water soluble), and a control in which no potassium was added. The experiment was a completely randomized design with three replications of each treatment.

Pearl millet was seeded on May 9, 1959 and thinned to 5 plants per pot. One cutting of millet was made on June 3, before the final harvest on August 10, 1959.

Experiment 2. Particle size and water solubility of potassium materials

Arredondo fine sand was weighed into three-gallon pots for the second greenhouse experiment. The potassium materials and treatments used in this experiment are given in Table 3.

Table 3--Potassium sources and treatments used in second greenhouse experiment.

Potassium source	Analysis	Particle size (mesh)	Percent water solubility	Lbs. per acre of K_2O applied
KCl	0-0-59	-35	100.0	200
KCl	0-0-60	-6+14	100.0	200
KCl	0-0-60	-3/8+4	100.0	200
KPO_3	0-47-28	-35	13.7	200
KPO_3	0-47-28	-3/8+4	13.0	200
KPO_3	0-47-28	-6+14	9.0	200
$K_2CaP_2O_7$	0-35-25	-35	7.2	200
$K_2CaP_2O_7$	0-35-25	-6+14	7.2	200
$K_2CaP_2O_7$	0-39-24	-3/8+4	7.5	200
Soil	---	---	---	---

Twenty pearl millet seed were planted on April 4, 1959 and later thinned to 5 plants per pot. Cuttings of millet were made on May 8 and May 30, and the final harvest on July 15, 1959.

Experiment 3. Cropping systems and leaching rates

The soil from the first greenhouse experiment was composited, thoroughly mixed, and weighed into three-gallon pots. Hydrated lime was mixed with the entire soil at a rate equivalent to one-half ton of $CaCO_3$ per acre. Variations were made in cropping practices and leaching rates. The crop variables included millet, radish, and fallow, while leaching variables included 3 1/2 and 7 inches of leachate collected per pot. The experiment was a 3 x 2 factorial in a completely randomized design with 4 replications of each treatment.

When the base application of fertilizer was applied, millet and radishes were broadcast and later thinned to 10 and 17 plants per pot, respectively. The crops were watered as needed for good plant growth for three weeks, and then 3 1/2 inches of water were leached through each pot to remove any excessive potassium from the soil. After a one-week period, 100 pounds of K_2O per acre, from KCl, was applied in solution to the soil surface. Leaching was begun 24 hours later by the addition of deionized water at a rate that delivered a total of 3 1/2 or 7 inches of leachate in 48 hours. The leachate was analyzed for potassium.

Laboratory Experiments

Two soils, Lakeland fine sand and Red Bay loamy fine sand were used in the laboratory leaching experiments. Analyses of these soils are given in Table 4.

Table 4--Analyses of Lakeland and Red Bay soils used in laboratory experiments.

Soil	Cation exchange capacity (me./100 g.)	Exchangeable bases (me./100 g.)		
		Ca	Mg	K
Lakeland	2.40	0.40	0.08	0.03
Red Bay	6.20	0.75	0.23	0.06

Soil leaching tubes 8 inches in depth and 1 1/4 inch inside diameter fitted with fritted glass filters, were used in these studies.

Air-dried soil was placed in each tube to a depth of 6 inches (175 grams of Lakeland and 160 grams of Red Bay soil per tube). After the potassium materials were mixed with the soil, deionized water was applied so that the same amount of leachate was collected from each tube.

Experiment 1. Time of contact of potassium materials with the soil

Three sources of potassium, KCl, KNO_3, and KPO_3, were added to the two soils in the tubes at a rate equivalent to 200 pounds of K_2O per acre. Potassium chloride and KNO_3 were added in solution and KPO_3 weighed directly into the tubes and mixed with the top centimeter of soil. Deionized water was then added in sufficient quantities to bring the soils to approximately field capacity.

The soil potassium fertilizer system was leached with deionized water after 0, 2, 7, and 14 days. Six inches of leachate, in one-inch increments, were collected and each increment analyzed for potassium content. The experiment was a 4 x 3 factorial in a completely randomized design with 3 replications of each treatment.

Experiment 2. Soil reaction

Bulk samples of Lakeland and Red Bay soils (pH 5.3) were placed in separate containers and sulfur or $Ca(OH)_2$ added to the various samples. After the sulfur or calcium treatments were thoroughly mixed with each soil sample, sufficient deionized water was added to bring the soils to approximately field capacity. The treated soil samples remained in incubation, at room temperature, for a period of three weeks at which time it was found that the pH levels of the soils had reached a new equilibrium point. The pH values of the two soils were as follows: Lakeland - 4.2, 5.3, 6.3, and 8.1; and Red Bay - 4.6, 5.3, 6.7, and 8.1. Soil from each adjusted sample was placed in the leaching tubes and potassium, from KCl, was added in solution at the rate of 200 pounds of K_2O per acre. Two days were allowed for reaction with the soil after which the tubes were leached with deionized water. Ten inches of leachate, in increments of 2 inches, were collected from each tube and each increment analyzed for potassium content. The experiment was a completely randomized design with 3 replications of each treatment.

Methods of Analysis

1. Ashing procedure for plant materials

One-gram samples of the oven dry plant tissue were ashed in a muffle furnace at 450° C., dissolved in 15 milliliters (ml) of 40 percent hydrochloric acid (HCl), evaporated to dryness, reheated in the muffle furnace at 450° C. for 30 minutes to 3 hours, dissolved in 1 ml. of concentrated HCl, evaporated to dryness, and made to volume with 0.1 normal HCl.

2. Analysis of plants and leachates

Calcium and potassium were determined by using a Beckman Model B, Flame photometer, with an oxygen-acetylene flame. The oxygen pressure was maintained at 10 psi and the acetylene pressure at 5 psi. The wave lengths employed were 622 mu and 768 mu for calcium and potassium, respectively. The readings were interpreted on a curve prepared with standard solution.

Magnesium was determined by passing an aliquot of the solution through an oxygen-hydrogen flame of a Beckman Model DU Flame Spectrophotometer, with a photomultiplier unit attached. The oxygen pressure was maintained at 12 psi and the hydrogen at 5 psi. The wave length employed was 282 mu. Readings were interpreted on a curve prepared with standard solutions.

Nitrate - Nitrogen was determined by the phenol-disulphonic acid method as described by Jackson (30).

Chlorine was determined by titration of chlorides with silver nitrate solution as described by Breland (11).

Sulfate - sulfur was determined turbidmetrically by the barium chloride method described by Chesnin and Yien (12).

3. Soil analysis

A Beckman zeromatic pH meter was used in determining pH values of leachates and soil samples. The pH readings of the soil samples were made from a 2:1 soil to water suspension.

Total exchange capacity was determined by the neutral normal ammonium acetate method according to procedures described by Russel and Stanford (59). The exchangeable bases (Ca, Mg, and K) from the ammonium acetate leachate were determined by the flame emission methods as previously described.

Statistical Methods

The data were analyzed by the analysis of variance methods described by Snedecor (60). Probability statements of comparisons among means are based on the Multiple Range Test (21).

RESULTS AND DISCUSSION

Data from the various experiments are grouped and discussed according to the type of experiment. They are presented in the following order: lysimeter experiments, three greenhouse experiments, and two laboratory experiments.

Lysimeter Experiments

Crop yields and potassium absorption

The yield of the winter crops (oats and cabbage) from Arredondo fine sand fertilized with 3 rates of KCl, applied as band or broadcast, are presented in Table 5. There was little yield response to rates of 60, 120, or 240 pounds of K_2O per acre from band applications to cabbage. When the potassium was added broadcast, however, the yield of cabbage was increased by each increment of KCl. The forage yield of oats from the low rate of KCl (60 pounds of K_2O per acre) was 720.7 g. as compared to 1015.8 g. from the 120 pounds of K_2O per acre application. This represents a 40 percent increase in forage yields for the heavier application. No further increases in forage yields of oats were obtained, however, when K_2O rates were increased from 120 to 240 pounds per acre.

During the following summer, the yield of sweet potatoes increased with each increment of K_2O from band and broadcast applications (Table 5). The plants from lysimeter 7 (low rate of K_2O) were damaged by rabbits, thus resulting in a lower yield from this

Table 5--Yield and potassium content of various crops grown on Arredondo fine sand in lysimeters with three rates of KCl in band and broadcast applications.

Lysimeter No.	Treatments: K added (g.)	Treatments: Lbs. acre K_2O	Placement	Crops	Dry wt. yields (g.)	K content of plants (percent)	Potassium uptake (g.)
				Winter crops			
1	11.30	60	Band	Cabbage	434.3	1.50	6.51
7	11.30	60	Broadcast	Cabbage	435.9	1.50	6.54
3	22.60	120	Band	Cabbage	422.1	2.55	10.76
11	22.60	120	Broadcast	Cabbage	524.1	2.05	10.74
2	45.20	240	Band	Cabbage	491.1	2.75	13.50
12	45.20	240	Broadcast	Cabbage	557.4	2.75	15.33
8	11.30	60	Broadcast	Oats	720.7	0.66	4.76
10	22.60	120	Broadcast	Oats	1015.8	0.86	8.74
6	45.20	240	Broadcast	Oats	919.4	1.35	12.41
				Summer crops			
1	11.30	60	Band	S. Potatoes*	1160.2	0.50	5.80
7	11.30	60	Broadcast	S. Potatoes	492.1	0.49	2.40
3	22.60	120	Band	S. Potatoes	1266.3	0.86	10.89
11	22.60	120	Broadcast	S. Potatoes	1074.1	0.89	9.57
2	45.20	240	Band	S. Potatoes	1922.8	1.18	22.60
12	45.20	240	Broadcast	S. Potatoes	1674.5	1.59	26.65
8	11.30	60	Broadcast	Millet	1346.6	0.46	9.20
10	22.60	120	Broadcast	Millet	1673.1	0.74	13.50
6	45.20	240	Broadcast	Millet	2075.9	0.74	27.56

*Harvested vines and marketable roots of sweet potatoes.

treatment than from the other plots. Sweet potato yields were higher from the band placements than from broadcast applications at all levels of potassium. Since these experiments were not designed for statistical analysis of the data, definite statements can not be made regarding the significance of these results. It was noted, however, that more marketable sweet potatoes were developed from the band placement of potassium than from the broadcast applications for each rates of KCl. The forage yield of millet also was increased by applications of 120 and 240 pounds of K_2O per acre. This increase in millet yield from the medium and high rates of KCl over the lowest rate (60 pounds of K_2O per acre) was 22.6 and 46.7 percent, respectively. Since sweet potatoes and millet are summer crops, normally requiring large amounts of potassium for good growth, it is not surprising that yield responses of both crops were obtained from each increment of KCl applied to this sandy soil of low available potassium.

The percent potassium content and total potassium uptake by the winter crops (cabbage and oats) and the summer crops (sweet potatoes and millet) are given in Table 5. The potassium content of all crops for both periods of study generally increased with each addition of KCl.

Potassium content of the above ground forage of all crops increased with each addition of potassium to the soil. The high potassium uptake by cabbage and oats receiving applications of 240 pounds of K_2O per acre without an accompanying increase in yield, indicated some luxury consumption of potassium by these crops.

There were no appreciable effects of band or broadcast placement on potassium absorption by cabbage. The total uptake of potassium by sweet potatoes was 17.8 percent higher from the broadcast than from the band placement of 240 pounds of K_2O per acre. This would indicate some luxury consumption by the plants from this treatment, since the yield resulting from the broadcast application was lower than from the band placement.

Effects of crops and potassium treatments on leaching of potassium

The amounts of rainfall that percolated through the soil and the potassium content of the leachates are presented in Table 6. There were 62.35 inches of precipitation during 11 months period of the study, with 29.20 inches falling during the winter and 33.15 inches during the summer months.

Calculations made from the data in Table 6 show that about one-third to four-fifths of the rainfall on the winter crops leached through the soils. The largest amounts of percolate - 78.9 percent - were collected from the three uncropped lysimeters, and the least amount, 36.0 percent, from lysimeter 6, where oats were grown. This indicates that 21.1 percent of the rainfall was lost through evaporation from the fallow soil and that at least 42.9 percent was absorbed by the oat crop. Water utilization by the various crops may have been somewhat greater than the differences in leaching losses between the fallow and cropped soils. Shading and lower average soil moisture under the crops probably reduced surface evaporation as compared to that encountered under fallow condition.

Table 6--The effect of broadcast and band placement of three rates of KCl on the leaching of potassium from Arredondo fine sand in lysimeters.

Treatments							
Lysimeter No.	Me. of K added	Lbs. acre K_2O	Placement	Crops	Rainfall passing through soil: Inches	Rainfall passing through soil: Percent	Me. of K in leachate
			Winter crops				
1	293.6	60	Band	Cabbage	19.13	65.5	11.44
7	293.6	60	Broadcast	Cabbage	18.76	74.3	10.94
8	293.6	60	Broadcast	Oats	11.54	39.5	7.02
9	293.6	60	Broadcast	Fallow	22.67	77.6	14.88
3	587.2	120	Band	Cabbage	19.89	68.1	10.43
11	587.2	120	Broadcast	Cabbage	19.04	65.2	11.86
10	587.2	120	Broadcast	Oats	10.07	36.7	9.41
5	587.2	120	Broadcast	Fallow	23.05	79.0	15.10
2	1174.4	240	Band	Cabbage	19.35	66.3	13.69
12	1174.4	240	Broadcast	Cabbage	18.36	62.9	13.54
6	1174.4	240	Broadcast	Oats	10.50	36.0	8.63
4	1174.4	240	Broadcast	Fallow	23.37	80.0	33.31
			Summer crops				
1	293.6	60	Band	S. Potatoes	14.01	42.3	14.95
7	293.6	60	Broadcast	S. Potatoes	16.64	50.7	16.71
8	293.6	60	Broadcast	Millet	12.32	37.2	10.62
9	293.6	60	Broadcast	Fallow	20.89	62.7	145.24
3	587.2	120	Band	S. Potatoes	13.91	42.0	44.85
11	587.2	120	Broadcast	S. Potatoes	13.66	41.2	24.97
10	587.2	120	Broadcast	Millet	11.14	33.6	16.94
5	587.2	120	Broadcast	Fallow	20.56	62.0	267.97
2	1174.4	240	Band	S. Potatoes	12.89	38.9	201.33
12	1174.4	240	Broadcast	S. Potatoes	12.48	37.7	89.91
6	1174.4	240	Broadcast	Millet	11.12	33.5	47.49
4	1174.4	240	Broadcast	Fallow	20.78	62.7	894.98

From one-third to two-fifths of the rain that fell on the summer crops leached through the soils. The largest amounts of percolate - 62.5 percent - were collected from the fallow lysimeters, and the least amount - 33.5 percent - from lysimeter 6, which was cropped to millet. Evaporation from the fallow lysimeters during this summer period was, therefore, 37.5 percent of the rainfall and crop utilization was about 29.0 percent of the rainfall for the millet crop. Approximately 42 percent of the summer rainfall leached through lysimeters planted to sweet potatoes, while the plants absorbed about 20.5 percent.

During the entire 11 months period of this study, an average of 43.74 inches, or 70.2 percent, of the rainfall passed through the fallow plots. An average of 32.87 inches, or 52.7 percent, leached through the plots planted to cabbage and later to sweet potatoes, while 22.22 inches, or 35.6 percent, was lost from the oats and millet plots. Crops growing on the soil markedly reduced the amount of percolate, since the water removed by transpiration and evaporation was much greater than by evaporation alone.

It can be seen from Table 6 that the leaching losses of potassium were quite small from all treatments during the winter period. There were no apparent differences in potassium content of the leachates from increasing rates of potassium on plots planted to cabbage. The average potassium leached from each rate of K_2O was less than 2 percent of the amount added from KCl. The loss of potassium from the highest rate of KCl on the oat plots was less than 1 percent of the amount applied in the fertilizer. Potassium leached from the fallow soil receiving 240 pounds of K_2O per acre (lysimeter 4) was 33.31 milliequivalents (me.), or 2.8 percent of the amount added.

These soils contained a relatively small amount of exchangeable potassium before treatments were applied as shown by the data in the first sampling period in Table 32 (Appendix). When added potassium was not removed by the plant, it was retained on the exchange complex of the soil, thereby preventing or reducing its loss by leaching. This is evident from the results of the second sampling period, (Table 32, Appendix), that the exchangeable potassium of soil samples was greater after the winter crops were harvested than that in the original samples. This increase was especially evident for plots receiving 240 pounds of K_2O per acre.

Much greater amounts of potassium were leached from the soil during the summer crop than for the winter period (Table 6). Potassium leaching from the sweet potato plots increased with each increment of KCl. However, the loss of potassium was quite small, with an average of only 5 percent of that added in the 60 pounds of K_2O treatment. The loss of potassium for millet plots ranged from 10.62 me. at the lowest rate to 47.49 me. at the highest rate of application. The greatest loss of potassium (894.98 me.) during the summer was from the fallow soil which received 240 pounds of K_2O per acre. This represents a total loss equivalent to 76.2 percent of the potassium added for the summer crops. However, it should be remembered that some residual potassium resulted from the previous winter treatments.

There were no apparent differences in the potassium content of the leachates from plots planted to cabbage, regardless of method of application. This was not true for the summer crop (sweet potato), where potassium loss from the 240 pounds of K_2O per acre rate was 201.33 me. from band as compared with 89.91 me. from broadcast applications. The former was more than 200 percent of the loss from broadcast applications. These differences in leaching losses of potassium may be partly attributed to greater absorption by the plants from the broadcast application. Since the cation exchange capacity of this soil was very low (around 2.5 me. per 100 gm. of soil), the increased contact between the applied potassium and the soil particles from the broadcast placement undoubtedly enhanced the retention of potassium.

As clearly shown by the data in Table 6, all crops were effective in reducing the leaching losses of potassium during both periods of study. The total loss of potassium from the fallow soil that received 480 pounds of K_2O per acre was 928.88 me. (Table 23, Appendix), or equivalent to 39.1 percent of the amount applied to the soil. In contrast, the leaching loss from lysimeter 12 (cabbage and sweet potatoes) was 215.01 me. (Table 31, Appendix), or 9.5 percent of the amount applied to the soil. Undoubtedly, crops reduce leaching losses of potassium through assimilation of this nutrient into their tissues, as well as through a reduction in water percolation through the soil, as a result of transpiration. The relative importance of these two functions probably varies with crops and soil conditions, but the following example may give some idea of their value in the conservation of potassium. The water leached through the fallow lysimeters represented 70.2 percent of the rainfall, while that lost from the cabbage and potato plots was 52.7 percent of rainfall. The crops reduced the loss by 25 percent. On the other hand, the potassium leached from fallow plots was equivalent to 39.1 percent of the 480 pounds of K_2O added, while that lost from the cabbage - potato plots was only 9.5 percent, or a reduction of 76 percent.

Milliequivalents of calcium, magnesium, nitrate-nitrogen, chloride, and potassium leached from the various lysimeters are given in Tables 20 through 31 (Appendix). Sulfates are not reported since the determinations were soon discontinued due to the small quantities found in the leachates.

In general, the calcium and magnesium content of the leachates increased with each increment of KCl added to the soil, although plant growth modified this pattern somewhat. The application of KCl to the soil resulted in an exchange of potassium ions with calcium and magnesium from the exchange complex. The calcium and magnesium chlorides formed by this exchange reaction were leached into the subsoil and out in the drainage water. Since the movement of cations in the soil is accompanied by an anion of a soluble salt, the added chlorine ions from the potassium salt probably accounts for the loss of bases in the heavier fertilized plots.

The losses of nitrogen from the soils by leaching were highest from the fallow plots and lowest from the lysimeters where crops were grown. The greatest loss (8328.5 me.) was from lysimeter 4, which was fallow throughout both test periods. The smallest nitrogen loss (2710.75 me.) was from lysimeter 10, where oats and millet were grown in the winter and summer months, respectively. About 35 percent more nitrogen was lost from fallow plots than from plots where cabbage and sweet potatoes were grown. Fifty to sixty percent more nitrogen was lost from fallow soils than from lysimeters planted to oats and later to millet. Nitrogen losses were related primarily to the quantity of nitrate-nitrogen in the soil, which in turn was influenced by the amount of nitrogen added as ammonium nitrate and by crop removal.

Crops had little effect on the movement of calcium, nitrogen, and chloride in the first 6 inches of gravitational water passing through the soil for the summer period. This was due to a period of heavy rainfall (7.20 inches in 5 days) immediately following the fertilizer applications and planting of the summer crops. In this connection, it was noted that after the crops were well established, another period of intense rainfall (over 5 inches in 6 days) did not greatly increase the leaching of ions from the soil. However, on the fallow soil the concentration of ions in the leachates increased markedly during this second period of heavy leaching rains. These data serve to emphasize the importance of a vigorously growing crop on the reduction of leaching losses of plant nutrients from sandy soils.

The concentrations of ions in the leachates collected from the sweet potato, millet, and fallow plots, receiving 240 pounds of K_2O per acre, are presented in Figures 1, 2, 3, and 4. Data are plotted in milliequivalents per liter against volume of leachates, so as to detect the probable salt forms in which the ions leached. The movement of calcium was apparently in the form of calcium nitrate and calcium chloride as may be observed in Figures 1, 2, 3, and 4. Since the soils were limed with calcium hydroxide before the summer treatments were applied, this probably accounts for the high concentrations of calcium in the first 6 to 7 inches of leachates. Magnesium, while not shown on the graphs, followed the same general pattern of leaching as calcium, except at a much lower rate, (Tables 20 to 31, Appendix). The potassium concentration crests followed fairly closely the nitrate peaks except that they were of a very much lower magnitude (Figures 1, 2, 3, and 4).

Potassium concentrations in the leachates from sweet potato plots were very low. The comparison between the potassium concentration in the leachates from the sweet potato plots with 240 pounds of K_2O per acre applied as band or broadcast may be seen in Figure 5. The concentration in the leachates was considerably higher from the band than from the broadcast application. It is apparent from Figure 3 that the concentration of potassium in the leachates from the millet plot was very insignificant when compared to the other ions. On the other hand, potassium concentration in the leachates from the fallow

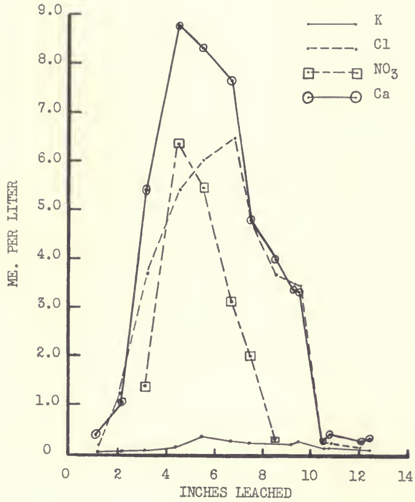

Figure 1--Concentration of ions in leachates from lysimeter planted to sweet potatoes with 240 pounds of K_2O per acre applied broadcast.

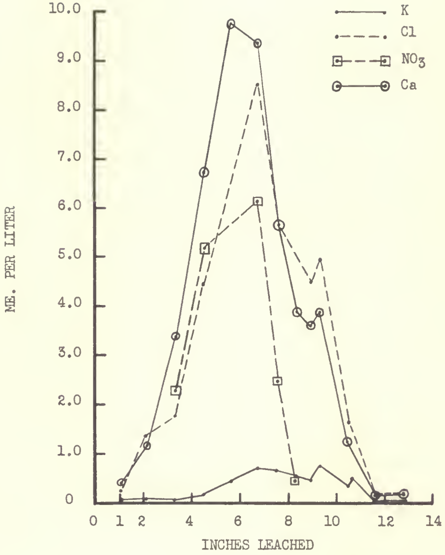

Figure 2--Concentration of ions in leachates from lysimeter planted to sweet potatoes with 240 pounds of K_2O per acre in band placement.

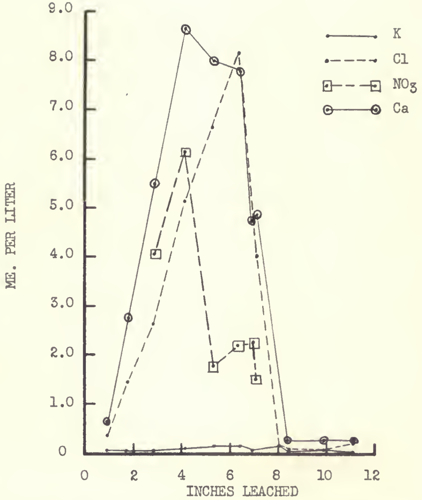

Figure 3--Concentration of ions in leachates from lysimeter planted to millet with 240 pounds of K_2O per acre applied broadcast.

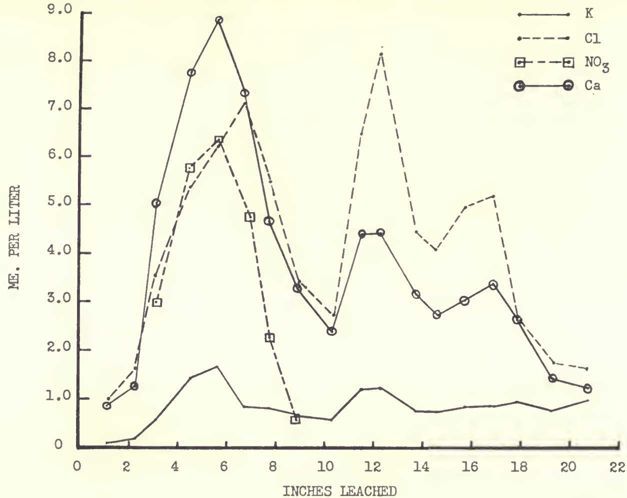

Figure 4--Concentration of ions in leachates from lysimeters from fallow soil with 240 pounds of K_2O per acre applied broadcast.

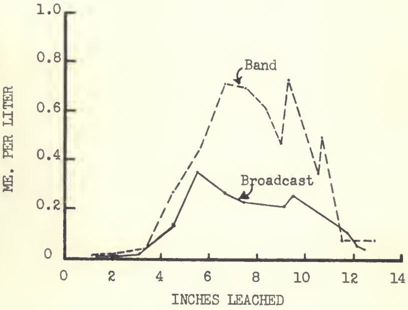

Figure 5--Concentration of potassium in leachates from lysimeter planted to sweet potatoes with 240 pounds of K_2O per acre applied in band or broadcast.

plot treated with 240 pounds of K_2O per acre was fairly high (Figure 4). Figure 6 shows the comparison of potassium lost from millet plots with that lost from fallow plots at the highest rate of potassium application.

Considerable amounts of inorganic colloidal material leached from the cropped lysimeters during both the winter and summer crop cycle. This material was identified as primarily a kaolinitic type clay colloid. The leachate from the fallow soils did not become turbid at any period. Differences in the amounts of colloidal clay leached from lysimeters planted to the various crops was not determined, however, the average for all cropped plots was 0.45 percent of the total volume of leachates. While the quantity of colloidal material moving through the four-foot soil profiles was not great for the short periods encountered in this experiment, it could be an important long-term soil management problem in sandy soils. The reason for the movement of the colloidal material is not known, but it is believed to be related to a deflocculation of soil particles due to a relative increase in monovalent cations. Morgan (46) reported on a similar condition in which the turbidity of lysimeter leachates increased as the percentage of monovalent cations on the exchange complex increased in relation to base exchange capacity. Considerably larger amounts of calcium and magnesium were removed by the combined forces of plant absorption and leaching from the cropped lysimeter than by leaching alone from the fallow plots. This may explain why practically no colloidal clay leached from the fallow plots, while considerable amounts were found in leachates from cropped lysimeters.

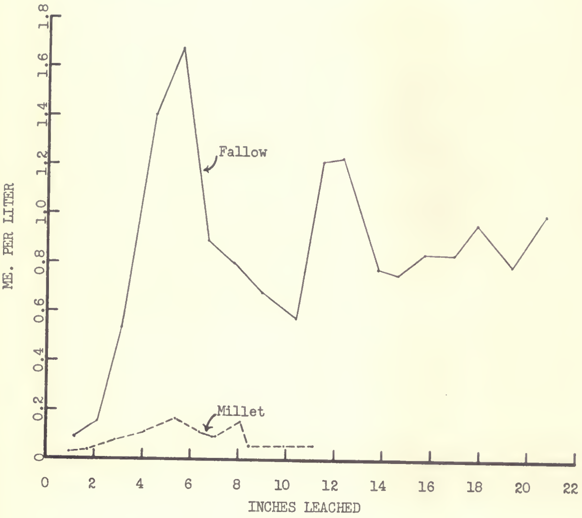

Figure 6--Concentration of potassium in leachates from fallow soil and from lysimeter planted to millet with 240 pounds of K_2O per acre applied broadcast.

The first loss of colloidal clay from the cropped lysimeters began during the fourteenth leaching period, on March 18, which was the result of heavy rainfall following a period of dry weather. The soils were all limed on May 7 and planted to the second crop on May 11. The leachates from all plots cleared on May 23 - the twenty-fourth leaching - which followed another period of heavy rainfall. The leachates remained clear until the thirty-third leaching period, August 11, at which time they again became cloudy. An examination of the chemical analysis of the leachates (Appendix Tables 20 to 31) indicates a drop in the content of calcium and magnesium in the leachates just prior to both periods in which the colloidal materials appeared. It was also noted that the milliequivalents of cations leached were considerably greater than that of the anions for which determinations were made during the period when the greatest amounts of colloidal clay leached from the lysimeters. The dispersed clay colloids may have combined with the cations and leached downward through the soil.

Greenhouse Experiments

Experiment 1. Associated anions of potassium fertilizers

Yields and potassium absorption from seven sources of potassium by millet grown in the greenhouse are presented in Table 7. Yield increases of above-ground dry matter for all potassium treatments were highly significant for both cuttings, as shown by the analysis of variance data (Table 37, Appendix). There were no significant

Table 7--The effect of 7 sources of potassium on the yield of dry forage and potassium absorption by millet grown on Lakeland fine sand in the greenhouse.

Treatments			Yield in gms. per pot			Potassium absorption, mg.		
No.	Potassium sources	Mg. K_2O applied per pot	Clippings 1st	Clippings 2nd	Total	Clippings 1st	Clippings 2nd	Total
1	Check (soil)	0	5.9	16.4	66.9	63.4	47.2	111.6
2	K_2CO_3	800	10.8	35.0	137.3	422.1	206.2	628.4
3	KPO_3*	800	10.4	31.2	124.8	466.1	204.5	670.6
4	KPO_3	800	9.7	28.7	115.4	373.3	149.3	524.6
5	KH_2PO_4	800	10.7	34.0	134.1	526.6	311.3	837.6
6	K_2SO_4	800	9.9	33.6	130.5	445.0	213.3	658.2
7	KCl	800	9.1	36.1	135.6	407.0	284.9	692.0
8	KNO_3	800	10.3	34.1	133.3	500.6	259.1	760.0

*13.7 percent water soluble, other source completely water soluble.

differences in yield among the seven potassium materials although the yield from KPO_3 (13.7 percent water soluble) was slightly less than the other potassium treatments. Apparently the relatively high applications of potassium used in this experiment (200 pounds of K_2O per acre) supplied ample potassium for good plant growth regardless of source. Furthermore, no visual symptoms of potassium deficiencies were observed on plants receiving any treatment except for the check pots where no potassium was added.

The comparison of the means for absorption of potassium by millet based on Duncan's Multiple Range Test is given in Table 8. This method of comparing a set of treatment means was used for all experiments that were statistically analyzed. The absorption of potassium by millet was significantly greater from all potassium sources than from the check pots for all cuttings (Table 8). The average potassium uptake was significantly less from KPO_3 (13.7 percent water soluble) than from the other potassium materials. This resulted from a slightly smaller yield and lower potassium content of the forage from this treatment. It appears that the availability of potassium for plant use from slowly-soluble potassium metaphosphates was lower than from the other sources, however, sufficient potassium was obtained by the plants for good growth at the high rate of application used in this test. There were no significant differences in potassium uptake from K_2CO_3, KPO_3 (99.7 percent water soluble), K_2SO_4, and KCl sources.

Potassium dihydrogen phosphate significantly increased potassium absorption by millet over all other treatments, except for the KNO_3 treatment. For the first cutting of millet, the percent potassium content of the forage from the KH_2PO_4 and KNO_3 treatments was 4.91 and 4.81, respectively. This would indicate some luxury consumption of potassium by millet from these treatments, since there was no significant increases in yield from the various potassium materials.

The milliequivalents (me.) of potassium and percent of applied K_2O that leached are given in Table 9. Considerably more potassium leached from all potassium sources than from the check where no potassium was added. Potassium, from the different materials, leached from the soil in varying degrees with the average order of leaching as follows: $KNO_3 > KCl > K_2SO_4 > KH_2PO_4 > KPO_3$ (99.7 percent water soluble)

Table 8--Test of significance for the effect of potassium sources on the milligrams of potassium absorbed by millet in Greenhouse Experiment No. 1.

First cuttings								
Treatment	1	4	7	2	6	3	8	5
Mean	63.4	373.3	407.0	244.1	445.0	466.1	500.6	526.6

Second cutting								
Treatment	1	4	3	2	6	7	8	5
Mean	47.2	149.3	204.5	206.2	213.3	259.1	284.9	311.0

Average of all cuttings								
Treatment	1	4	2	6	3	7	8	5
Mean	55.3	262.3	314.2	329.1	335.3	346.0	380.0	418.8

Notes:

Any two means underlined by the same line are not significantly different. Any two not underlined by the same line are significantly different at the 5 percent level (See Table 37, Appendix for the A.O.V.).

Table 9--Potassium leached from Lakeland fine sand cropped to millet in the greenhouse expressed as milliequivalents and percent of that added from seven potassium sources.

No.	Treatments: Potassium[2] source	Me. of K leached[1]: Leachings 1st	2nd	3rd	Total	Percent applied K leached: Leachings 1st	2nd	3rd	Total
1	Check (soil)	0.49	0.12	0.19	0.80	0	0	0	0
2	K_2CO_3	0.65	0.22	0.41	1.28	0.74	0.49	1.07	2.34
3	KPO_3 (3)	0.71	0.28	0.33	1.32	1.07	0.78	0.68	2.53
4	KPO_3	0.83	0.23	0.32	1.38	1.66	0.54	0.63	2.83
5	KH_2PO_4	0.88	0.34	0.33	1.55	1.90	1.07	0.68	3.65
6	K_2SO_4	1.86	0.24	0.42	2.52	6.69	0.59	1.12	8.40
7	KCl	2.24	0.25	0.37	2.86	8.55	0.63	0.88	10.60
8	KNO_3	3.27	0.40	0.39	4.06	13.57	1.37	0.98	15.92

(1) approximately 4 inches of water passed through soil for each leaching.
(2) 20.45 me. of potassium applied from each source.
(3) 13.7 percent water soluble, others completely water soluble.

$$\text{Percent applied K leached} = \frac{\text{me. K leached - me. K leached from check}}{\text{me. K applied}}.$$

> KPO_3 (13.7 percent water soluble) > K_2CO_3. Potassium carbonate loss was significantly less than from the other potassium materials (Table 10). There were no significant differences in amounts of potassium leached among the three potassium phosphate sources. The amounts of potassium leached from K_2SO_4 were significantly higher than from the other sources, with the exception of KCl and KNO_3. The amount of potassium leached from KNO_3 was significantly greater than all other treatments. This was probably due to the higher concentration of anions, in the

Table 10--Test of significance for the effect of potassium sources on the milliequivalents of potassium leached from the soil in Greenhouse Experiment No. 1.

First leaching

Treatment	1	2	3	4	5	6	7	8
Mean	0.49	0.65	0.71	0.83	0.88	1.86	2.24	3.27

Second leaching

Treatment	1	2	4	6	7	3	5	8
Mean	0.12	0.22	0.23	0.24	0.25	0.28	0.34	0.40

Third leaching

Treatment	1	4	3	5	7	8	2	6
Mean	0.19	0.32	0.33	0.33	0.37	0.39	0.41	0.42

Average for all leachings

Treatment	1	2	3	4	5	6	7	8
Mean	0.80	1.28	1.32	1.38	1.55	2.52	2.86	4.06

Notes:

Any two means underlined by the same line are not significantly different. Any two not underlined by the same line are significantly different at the 5 percent level (See Table 37, Appendix, for the A.O.V.).

nitrate form, present in this soil, since a uniform base application of ammonium nitrate was added to all pots before the millet was planted. Volk and Bell (70) reported that potassium, in the presence of calcium and magnesium, tends to leach more readily with nitrate than with chloride or sulfate anions. Moreover, there were smaller amounts of calcium and magnesium leached from this treatment than from the K_2SO_4 and KCl treatments, for the first leaching periods, as shown in Table 37 (Appendix).

A clearer picture of potassium leaching may be gained from examining the potassium losses in relation to the amount added as fertilizer. The percent of K_2O applied that leached ranged from 2.3 from K_2CO_3 to 15.9 percent from KNO_3. In general, potassium losses from the three leachings of about 12 inches of water were so small as to be unimportant from K_2CO_3 and from the potassium phosphate sources. Leaching losses from K_2SO_4, KCl, and KNO_3 were 8.4, 10.6, and 15.9 percent, respectively, with the greater part of this loss occurring during the first leaching period (Table 9).

After the millet crop was well established, very little potassium leached from any treatment. This beneficial effect of crops in preventing potassium losses by leaching from sandy soils has been reported by several workers (27, 65, 67). The low retention of applied potassium by the exchange complex of this sandy soil and the efficient uptake of potassium by the millet crop, indicates that applications of potassium to such soils in excess of crop need are not practical. Furthermore, heavy potassium applications would probably fail to build up a potassium reserve in this soil and would result in loss of potassium through luxury consumption by the crop.

The effect of the associated anions of the various materials on the leaching losses of potassium was significant for the first leachings, but was of very little consequence during the other leachings. This is evident from the data presented in Table 9, showing that the potassium lost during the first leaching fairly well paralled the total lost during all three leachings. This is also shown graphically in Figure 7. Leaching of the nitrate, chloride, and sulfate anions (Table 32, Appendix) followed the same pattern as described by Gammon (36) and other investigators (40,41). Most of the applied chlorine from the KCl source was removed in the first leaching. However, the sulfates, from K_2SO_4, were retained in the soil more securely, with 57.6 percent removed in the first leaching and 34.8 percent in the second leachings. Only traces of phosphorus were found in the leachates from any of the treatments. This is in agreement with data reported by Ayres and Hagihara (4) on the leaching of phosphorus from Hawaiian soils when treated with several potassium phosphate materials.

The potassium materials exhibited marked effects on the amounts of calcium and magnesium leached from the soil (Table 32, Appendix). Large quantities of calcium leached from the chloride, sulfate and nitrate materials and from the soil where no potassium was added. The large amounts of calcium leaching from salts of these

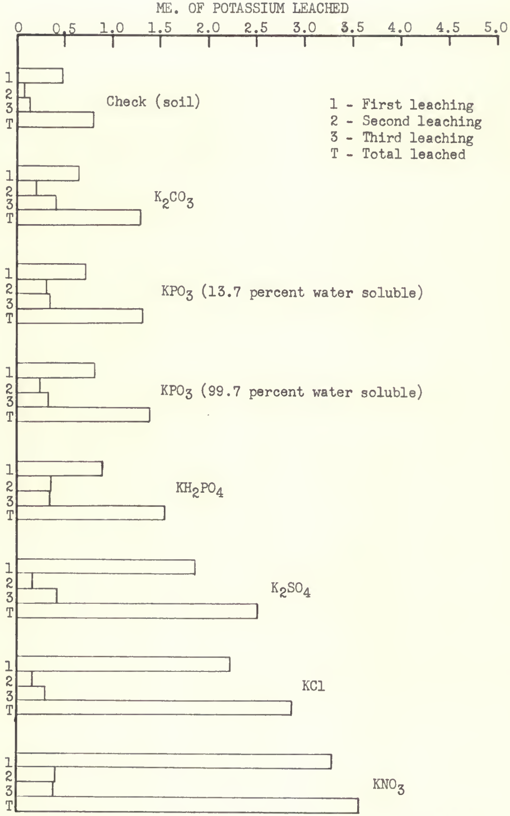

Figure 7--Milliequivalents of potassium leached from Lakeland fine sand cropped to millet in the greenhouse receiving various sources of potassium.

potassium sources may be attributed to the associated anions of these materials combining with calcium in the soil and subsequently leaching in the form of $CaCl_2$, $CaSO_4$, and $Ca(NO_3)_2$. It is to be noted that while the same rate of NH_4NO_3 was added to all pots, the amounts of nitrogen leached from soils of the check plots were higher than from the other treatments, excluding the KNO_3 source. Therefore, calcium and other cations could also leach in the nitrate form from the check treatment. Magnesium leached from the soil in the same general pattern as calcium, except at a very much lower level.

The amounts of calcium leached were greatly reduced by applications of the potassium phosphate materials (Table 32, Appendix). The amounts leached from KH_2PO_4 were 12.64 me. compared to 36.52 me. from KCl. Ayres and Hagihara (4) suggested that the addition of potassium phosphate materials may result in the formation of insoluble calcium and magnesium phosphates, thereby reducing the leaching of these bases from the soil. This may also account for the reduction in leaching of potassium due to the substitution of potassium for calcium and magnesium on the exchange complex of the soil.

When K_2CO_3 is added to an acid soil, the potassium ions are taken up by the soil due to the neutralization of the exchangeable hydrogen ion by the bicarbonate ion. The hydrogen ions are then removed by leaching as H_2CO_3 or by decomposition into CO_2 and H_2O. In this way, potassium may be absorbed directly on the soil exchange complex without a subsequent replacement of another cation, such as calcium. This may account for the reduced leaching losses of calcium and magnesium, as well as potassium, from the K_2CO_3 treatment.

Experiment 2. Particle size and water solubility of potassium materials

The yield, potassium content and total potassium absorbed by millet plants to which potassium sources of varying particle size and water solubility had been applied are shown in Tables 11 and 12. All treatments significantly increased yields over the check soil to which no potassium was added (Table 38, Appendix). There were no significant differences in millet yields among pots receiving any of the potassium materials. This is in agreement with results from the first greenhouse experiment where it was found that millet growth was fairly constant from applications of 200 pounds of K_2O per acre regardless of the source of potassium.

Since the potassium sources varied in particle size from -35 to -3/8 + 4 mesh and the percent water solubility from 7.2 to 100, differences might be expected in potassium content of plants receiving the various treatments. This was not the case, however, except for the first harvest where millet, receiving the large particle (-3/8 + 4 mesh) KPO_3 and $K_2CaP_2O_7$, was significantly lower in potassium content than in plants receiving the other material (Table 38, Appendix). After the first clipping of millet, the potassium content of the plants was fairly uniform from all treatments.

Total potassium uptake by the plants was significantly higher in all pots receiving the potassium sources than in the check soil.

Table 11--Yield of millet grown in the greenhouse on Arredondo fine sand receiving three potassium sources of varying water solubility and particle size.

Treatments				Yields in gms./pot			
No.	Potassium* source	Mesh size	Percent water solubility	Clippings 1st	2nd	3rd	Total
1	Check (soil)	---	---	10.5	5.6	11.0	27.1
2	KCl	-35	100.0	16.2	7.8	14.5	41.5
3	KCl	-6+14	100.0	16.6	8.5	16.7	43.8
4	KCl	-3/8+4	100.0	14.6	8.3	15.4	39.3
5	KPO_3	-35	13.7	16.6	8.1	15.5	41.2
6	KPO_3	-6+14	13.0	16.7	8.7	17.7	43.1
7	KPO_3	-3/8+4	9.0	14.6	8.3	15.6	39.5
8	$K_2CaP_2O_7$	-35	7.2	17.1	9.5	15.9	42.5
9	$K_2CaP_2O_7$	-6+14	7.2	17.5	8.9	16.4	42.8
10	$K_2CaP_2O_7$	-3/8+4	7.5	16.1	7.4	18.0	44.5

*800 mg. of potassium applied from each source.

Significantly less potassium was absorbed from the largest particle size of KPO_3 and $K_2CaP_2O_7$ than from the other potassium sources, as shown in Table 13. The significance of potassium uptake may be shown more clearly when expressed as percent of the applied potassium absorbed by the plants. These values ranged from 76.8 percent from the large particle size to 41.1 percent from the smallest size of KPO_3. These results clearly indicate that the slowly water soluble potassium phosphate materials used in this experiment were equally effective as the completely water soluble KCl in supplying potassium to the plants (Table 13).

Table 12--Potassium content and absorption by millet grown in the greenhouse on Arredondo fine sand receiving three potassium sources of varying water solubility and particle size.

Treatments				Percent K content			K uptake in Milligrams				Percent applied K absorbed by plants
				Clippings			Clippings				
No.	Potassium* source	Mesh size	Percent water solubility	1st	2nd	3rd	1st	2nd	3rd	Total	
1	Check (soil)	---	---	0.58	0.49	0.27	60.3	26.4	29.2	115.9	0
2	KCl	-35	100.0	3.05	1.15	0.53	488.7	100.7	75.1	664.5	68.4
3	KCl	-6+14	100.0	2.64	1.17	0.39	437.2	140.8	64.9	642.9	65.6
4	KCl	-3/8+4	100.0	3.22	1.96	0.45	475.1	109.3	70.8	685.2	75.5
5	KPO_3	-35	13.7	2.72	1.83	0.57	434.2	143.6	86.7	664.5	71.4
6	KPO_3	-6+14	13.0	2.24	1.97	0.69	403.7	168.6	109.5	681.8	70.9
7	KPO_3	-3/8+4	9.0	1.72	1.39	0.48	251.1	114.4	70.4	435.9	41.1
8	$K_2CaP_2O_7$	-35	7.2	2.89	1.50	0.59	492.8	142.1	93.8	728.7	76.8
9	$K_2CaP_2O_7$	-6+14	7.2	2.34	1.53	0.53	406.5	134.2	86.7	627.4	63.3
10	$K_2CaP_2O_7$	-3/8+4	7.5	1.91	1.58	0.49	306.2	115.4	85.7	507.3	48.4

*800 mg. of potassium applied from each source.

Table 13--Test of significance for the effect of potassium sources on the milligrams of potassium absorbed by millet in Greenhouse Experiment No. 2

Average of all cuttings										
Treatment	1	7	10	9	3	2	5	6	4	8
Mean	38.6	145.3	169.1	209.1	214.3	221.5	221.5	227.3	228.2	243.9

Notes:

Any two means underlined by the same line are not significantly different. Any two means not underlined by the same line are significantly different at the 5 percent level. (See Table 38, Appendix for A.O.V.).

The amounts of potassium leached from the soil as affected by the various potassium sources are given in Table 14. Potassium losses were significantly higher from soluble KCl than from the slightly-soluble source of KPO_3 and $K_2CaP_2O_7$, regardless of particle sizes. A total of 7.28 me. of potassium leached from pots receiving the large particle size of $K_2CaP_2O_7$. This represents a 600 percent difference in these two sources. The comparisons of the differential in potassium leaching among the various materials are shown in Figure 8. Potassium losses were significantly larger from the KCl treatments than from the potassium phosphate materials (Table 15). The amount of potassium leached from the largest size of KCl was also significantly

Table 14--Potassium leached from Arredondo fine sand cropped to millet in the greenhouse, expressed as milliequivalents and percent of that added from 3 potassium sources of varying water solubility and particle size.

	Treatments			Me. of potassium in leachings				Percent applied potassium in leachings			
No.	Potassium* source	Mesh size	Percent water solubility	1st	2nd	3rd	Total	1st	2nd	3rd	Total
1	Check (soil)	---	---	0.30	0.21	0.25	0.76	---	---	---	---
2	KCl	-35	100.0	2.84	2.30	0.61	3.75	12.4	0.4	1.8	14.6
3	KCl	-6+14	100.0	2.62	0.25	0.83	3.70	11.4	0.2	2.8	14.4
4	KCl	-3/8+4	100.0	5.96	0.35	0.97	7.28	26.3	0.7	3.5	30.5
5	KPO_3	-35	13.7	0.52	0.77	0.61	1.90	1.1	2.7	1.8	5.6
6	KPO_3	-6+14	13.0	0.62	0.57	0.81	2.00	1.6	1.8	2.7	6.1
7	KPO_3	-3/8+4	9.0	0.34	0.25	0.76	1.35	0.2	0.2	2.5	2.9
8	$K_2CaP_2O_7$	-35	7.2	0.61	0.31	0.50	1.42	1.5	0.5	1.2	3.2
9	$K_2CaP_2O_7$	-6+14	7.2	0.56	0.18	0.50	1.24	1.3	0	1.4	2.7
10	$K_2CaP_2O_7$	-3/8+4	7.5	0.20	0.27	0.73	1.20	0	0.3	2.4	2.6

*20.45 me. of potassium applied from each source.

$$\text{Percent applied K leached} = \frac{\text{me. K leached - me. K leached from check}}{\text{me. K applied}}$$

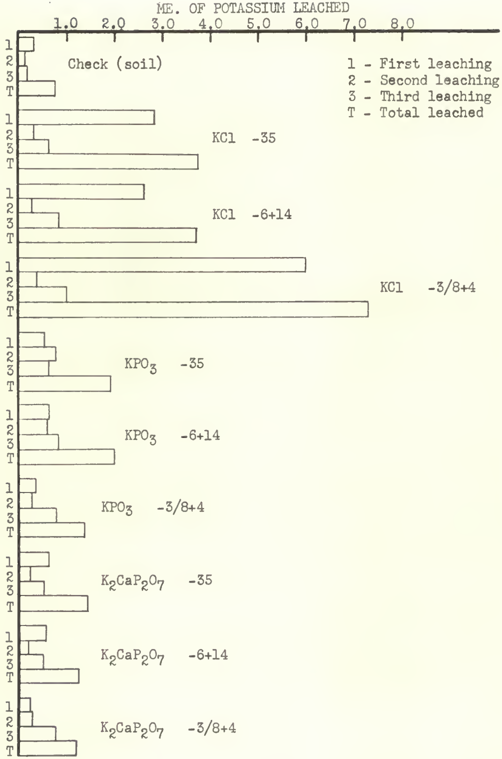

Figure 8--Milliequivalents of potassium leached from Arredondo fine sand cropped to millet in the greenhouse, receiving 3 potassium sources of varying water solubility and particle size.

Table 15--Test of significance for the effect of potassium sources on the milliequivalents of potassium leached from the soil in Greenhouse Experiment No. 2.

First leachings

Treatment	10	1	7	5	9	8	6	3	2	4
Mean	0.20	0.30	0.34	0.52	0.56	0.61	0.62	2.62	2.84	5.96

Second leachings

Treatment	9	1	7	3	10	2	8	4	6	5
Mean	0.18	0.21	0.25	0.25	0.30	0.31	0.35	0.35	0.57	0.77

Average of all leachings

Treatment	1	10	9	7	8	5	6	3	2	4
Mean	0.25	0.40	0.41	0.45	0.47	0.63	0.67	1.23	1.25	2.43

Notes:

Any two means underlined by the same line are not significantly different. Any two not underlined by the same line are significantly different at the 5 percent level. (See Table 38, Appendix).

larger than from the smaller size KCl sources. There was no significant difference in leaching losses of potassium among the potassium phosphate sources.

The amounts of potassium leached, as the percent of K_2O applied, is presented in Table 14. The percent of applied potassium that leached from the various sources ranged from 2.6 to 30.5 percent from the largest particle sizes of KPO_3 and KCl, respectively. A total of 14.6 percent leached from -35 mesh KCl and 14.4 percent from -6+14 mesh KCl. Potassium losses were very low from the potassium phosphate materials, ranging from 2.6 for the large particle size of $K_2CaP_2O_7$ to 6.1 from the -6+14 mesh for KPO_3. These results are in agreement with the data reported previously from the greenhouse experiment. The most striking results obtained in this study were the effect of increasing particle size of KCl on the leaching of potassium. When the particle size of KCl was increased to -3/8+4 mesh, potassium losses were increased over 100 percent by this treatment as compared with those from the smaller particle sizes of KCl. The increased leaching from this treatment may be attributed to a combination of several factors. A relative small number of pellets of the large size KCl resulted in a high concentration of soluble potassium in contact with a small volume of soil. Since the soil had a low cation exchange capacity (3.60 me. per 100 g.), the exchange positions near each pellet of KCl became saturated with potassium. Therefore, the severe leaching to which the soil was subjected carried the potassium downward before it could diffuse laterally through the soil and be retained on other exchange positions. The smaller particles of KCl were in contact with a larger volume of soil increasing the opportunity for retention on the exchange complex. It may be concluded from these data that increasing the particle size of completely water-soluble potassium material, such as KCl, would probably result in increased leaching losses on sandy soils. On the other hand, slightly soluble potassium materials may leach less readily when applied as relatively large particles than when applied as a powder.

The results obtained in this experiment and the previous greenhouse experiment indicate that the potassium phosphate materials may have considerable value as a potassium source in sandy soils due to its resistance to leaching. However, these materials need to be tested more thoroughly in field experiments conducted over a period of years, and their cost per unit of K_2O compared with that of KCl or K_2SO_4, before definite conclusions are made as to their value as potassium fertilizer sources.

The total milliequivalents of ions in the leachates from all treatments are presented in Table 35 (Appendix). Treatment effects on the leaching patterns of the various ions were very similar to those previously mentioned in the first greenhouse experiment. Sulfate content of the leachate was not measured, as it was added to all treatments in very small amounts. Since leaching data for calcium, magnesium, nitrogen, and chloride ions were very similar to those from the first greenhouse experiment, they are not discussed in this section.

Experiment 3. Cropping systems and leaching rates

The effect of cropping systems on the amounts of potassium leached from Lakeland fine sand was studied in the greenhouse. The soil in the pots was uniformly fertilized and either planted to millet, radishes, or left fallow. After three weeks to allow for the root systems of the plants to become well established, 3 1/2 inches of deionized water were passed through each pot. The amounts of potassium removed by this leaching are shown in Figure 9. Statistical analyses of these data show highly significant differences in the amounts of potassium leached from the soil among the fallow, radish, and millet treatments. Since nitrogen was added uniformly to all pots, a high concentration of nitrate ions might account for the large loss of potassium from the fallow soil. The differences in potassium leached from the two crops may be attributed to greater absorption of potassium by the millet.

One week following the first leaching, potassium chloride was added in solution equivalent to 100 pounds of K_2O per acre to all pots. Leaching was begun 24 hours later and 3 1/2 or 7 inches of water was passed through each soil. The amounts of potassium that leached from the fallow, radish, and millet treatment with 3 1/2 inches of water were 425.1, 42.3, and 15.4 mg., respectively (Table 16). From pots leached with an additional 3 1/2 inches of water, the amount of potassium lost from the fallow soil increased from 425.1 to 790.8 mg., or an increase of 85.9 percent. Increasing the intensity of leaching

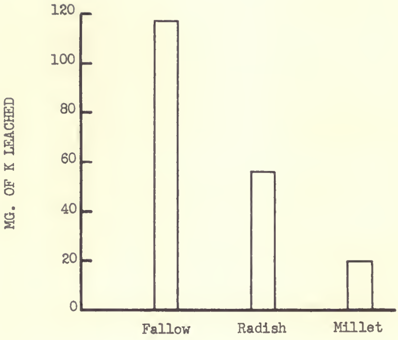

Figure 9--Milligrams of potassium in 3 1/2 inches of leachates collected from Lakeland fine sand in the greenhouse with millet, radish and fallow cropping practices.

Table 16--The effect of two leaching rates on the amounts of potassium leached from Lakeland fine sand in the greenhouse, with fallow, radish and millet crops.

Leaching	Milligrams of potassium leached		
Inches	Fallow	Radish	Millet
3 1/2	425.1	24.3	15.4
7	790.8	30.8	43.1

from 3 1/2 to 7 inches also increased the amount of potassium lost from soils growing millet and radish crops. However, the total amounts of potassium lost as a result of either rate of leaching were very small.

Since there was no check treatment included in this experiment, the percent of added potassium leached could not be calculated from the data. However, a total of 480 mg. of potassium were added to each pot and 88.6 and 164.8 percent of this amount leached from the fallow soil with 3 1/2 and 7 inches of water, respectively. Since larger amounts of potassium were leached from the soil by the 7-inch increment than were added, it is obvious that considerable native soil potassium was removed by this intensive leaching.

There was a highly significant interaction between crops and leaching rates in the experiment (Table 39, Appendix). This interaction indicates that millet and radishes do not affect the movement of potassium in the same manner at the two intensities of leaching. However, as pointed out previously, the amounts of potassium that leached from soils growing the two crops were very insignificant for this study. From the data in Table 15 and by examination of the analysis of variance means in Table 39 (Appendix), it is clearly evident that the fallow treatment contributed the major variance in potassium losses in leaching in this experiment. These results again point out the importance of crops, and particularly the type of root systems of crops in retention of soluble potassium against the leaching action of heavy rains from a sandy soil. Under field conditions, very little potassium would be lost by leaching from normal applications of KCl to plants with well-established root systems.

Laboratory Experiments

Experiment 1. Time of contact of potassium materials with the soil

Three potassium sources were added to Lakeland and Red Bay soils and then the soil-fertilizer system leached after various periods of incubation. The amounts of potassium leached from the soils as affected by the time of soil-fertilizer contact are given in Table 17. The Red Bay soil retained a higher percentage of the added potassium from all treatments than the Lakeland soil. There were relatively small amounts of potassium leached from KPO_3 from either soil. The amounts of potassium leached from KCl and KNO_3 were about the same, except for the long contact period with Lakeland soil.

Table 17--Effect of contact time of soil-potassium materials on the milligrams of potassium leached from Lakeland and Red Bay soils in the laboratory.

Potassium materials	Time of soil-fertilizer contact			
	0 days	2 days	7 days	14 days
		Lakeland f.s.		
Soil (check)	0.37	0.28	0.30	0.41
KCl	8.38	8.43	7.68	12.26
KNO_3	8.88	7.40	6.11	8.89
KPO_3	1.45	1.55	1.54	2.56
		Red Bay l.f.s.		
Soil (check)	1.08	0.83	1.09	2.44
KCl	2.53	2.28	2.39	5.37
KNO_3	2.68	2.31	1.96	4.67
KPO_3	1.38	2.17	1.44	3.02

Under these conditions, considerable more potassium leached from the KCl than from the KNO_3 treatment. These results are in general agreement with data from greenhouse experiments in which the relative order of potassium leaching from various potassium materials was determined.

For the Lakeland soil, the amount of potassium leached from KCl ranged from 7.68 mg. after 7 days to 12.26 mg. after 14 days of contact, or the equivalent of 55.1 and 81.7 percent of the applied potassium, respectively. This is in contrast to the results from the Red Bay soil, where the percent of added potassium leached after the 7- and 14-day incubation periods was 11.0 and 22.2 percent, respectively. These data are in general agreement with other workers

(28, 69) who have demonstrated that potassium is less subject to leaching from soils with higher clay content than from sandy soils.

The increase in potassium leached from the three materials after a 14-day soil-fertilizer contact was probably due to an accumulation of nitrate-nitrogen in the soil during this period of incubation. Apparently large amounts of the potassium added as KCl, KNO_3, and KPO_3 combined with the extra nitrate anions and leached as KNO_3.

There was a highly significant interaction between potassium materials and the soil-fertilizer contact dates reflecting a difference in the amounts of potassium leached from KCl and KNO_3 at various leaching dates (Figure 10). Slightly larger amounts of potassium leached from the KNO_3 source than from KCl for the first leaching dates, whereas, the reverse was true for the last two soil-fertilizer contact leaching dates.

The amounts of potassium removed from Lakeland and Red Bay soils by 1-inch increments of water after 0 and 14 days of incubation are shown in Figures 11 and 12, respectively. In general, the leaching patterns for KCl and KNO_3 were similar. An average of 60 percent of the total potassium applied to the soil was removed in the first two inches of water, and over 80 percent was removed after only three inches of water had passed through the soil column. The amounts of potassium leached from the KPO_3 material were small but rather uniformly distributed in all six leachings.

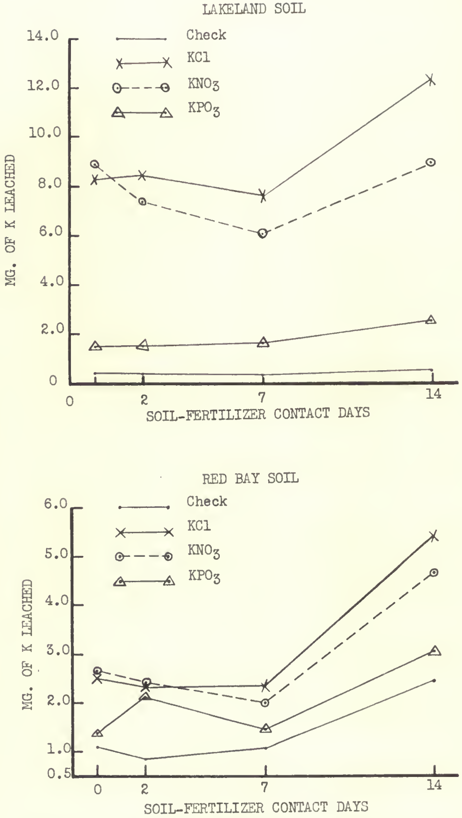

Figure 10--The effect of soil-fertilizer contact period on the amount of potassium leached from Lakeland and Red Bay soils in the laboratory.

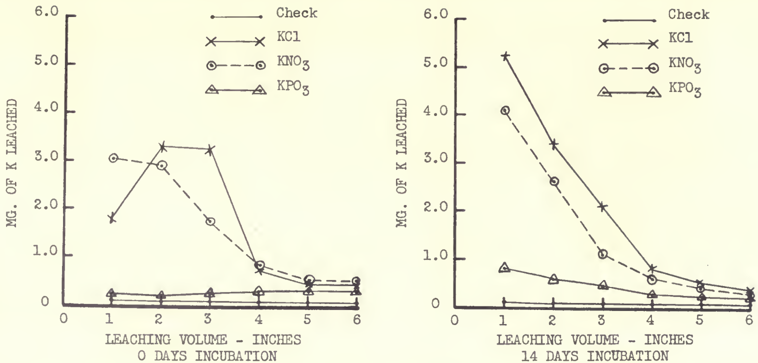

Figure 11--Milligrams of potassium leached by one inch increments of leachates from 3 potassium materials applied to Lakeland fine sand in the laboratory.

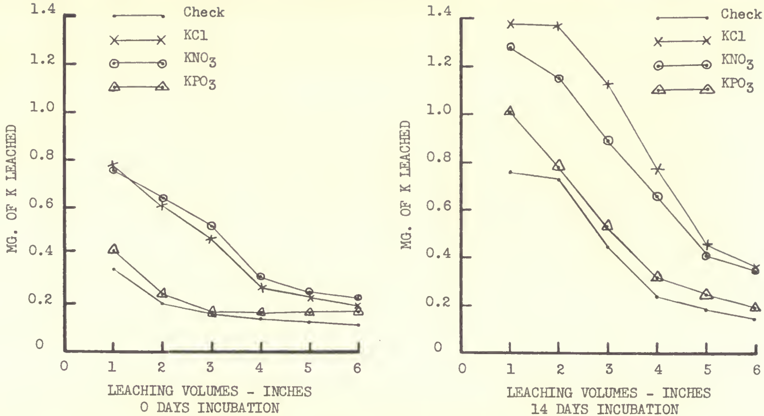

Figure 12--Milligrams of potassium leached by one inch increments of leachates from 3 potassium materials applied to Red Bay loamy fine sand in the laboratory.

Experiment 2. Soil reaction

The effects of soil pH on the amount of potassium leached, on the calculated percentage of added potassium leached, and on the cation exchange capacity of the soils are presented in Table 18. There were significant differences in amounts of potassium leached from the Lakeland soil adjusted to the various pH levels, as shown in Table 19. The amount of potassium leached from Lakeland soil ranged from 6.0 mg. at pH 6.3, or a total of 41.4 percent of that added, to 18.0 mg. at pH 8.3, or 124.1 percent of the amount added. A total of 10.7 mg., or 73.1 percent of the added potassium leached from the untreated Lakeland soil with a pH of 5.3. In contrast, the original Red Bay soil (pH 5.3) retained 88 percent of the added potassium against loss by leaching. The amounts of potassium leached from Red Bay soil ranged from 1.1 mg. at pH 6.7 to 5.5 mg. at pH 4.6. These amounts of potassium represents 8.3 and 41.3 percent of the added potassium for the two soil pH levels, respectively. There was no significant difference in the amounts of potassium leached from Red Bay soil at the higher pH levels. When the soil pH was lowered to 4.6, significantly larger amounts of potassium leached from the soil in this acid condition than at the higher pH levels.

The increase in amounts of potassium leached from Lakeland soil when the pH was raised to 8.3 was probably due to the high concentration of calcium ions replacing potassium from the exchange complex of the soil by mass action. Peech and Bradfield (54) reported

Table 18--Effect of varying soil pH on leaching of potassium and cation exchange capacity of Lakeland and Red Bay soils in the laboratory.

Soil pH	Milligrams of K leached	Percent of added K that leached	Cation exchange capacity me./100 g.
		Lakeland soil	
4.2	16.2	111.7	2.10
5.3	10.7	73.1	2.67
6.3	6.0	41.4	3.03
8.3	18.0	124.1	3.28
		Red Bay soil	
4.6	5.5	41.3	7.07
5.3	1.6	12.0	8.95
6.7	1.1	8.0	10.76
8.1	1.8	13.5	8.78

Table 19--Test of significance for the effect of varying the soil pH on the milligrams of potassium leached from Lakeland and Red Bay soils in the laboratory.

		Lakeland sand		
Soil pH	6.3	5.3	4.2	8.3
Means	6.0	10.7	16.2	18.0
		Red Bay fine sand		
Soil pH	6.7	5.3	8.1	4.6
Means	1.1	1.6	1.8	5.5

Notes:

Any two means underlined by the same line are not significantly different. Any two not underlined by the same line are significantly different at the 5 percent level. (See Table 41, Appendix for A.O.V.).

this adverse effect of excessive calcium in the soil on the leaching of potassium. There was a small increase in amounts of potassium leached at pH 8.1 from the Red Bay soil, however, it was not significantly higher than the other treatments (Table 19).

The cation exchange capacities (C.E.C.) of the soils were determined with neutral normal ammonium acetate extracting solution. The C.E.C. increased with each rise in pH for the Lakeland soil (Table 18). The C.E.C. increased from 2.10 to 3.28 milliequivalents per hundred grams of soil when the soil pH was increased from 4.2 to 8.3. This is an increase of 56 percent. The C.E.C. of the Red Bay soil increased from 7.07 me. at pH 4.6 to 10.76 me. at pH 6.7. However, the exchange capacity declined when the soil reaction was raised from pH 6.7 to 8.1 (Table 18). These results are in general agreement with those reported by Thomas and Coleman (63). They stated that when liming materials are added to acid soils, their capacity for holding positively charged ions increases in most cases.

The relation of soil pH to the leaching of potassium is shown graphically in Figure 14. The loss of potassium in water percolated through these two soils decreased as the soil pH was increased to around 6.5. However, when the soil was limed to above pH 8.0, the loss of potassium was greater than at pH 6.5. The effect of liming acid soils on the retention of potassium may be due to a number of factors. However, the factors that appear to be of primary importance are: a) the mass-action effect based upon easier displacement of calcium

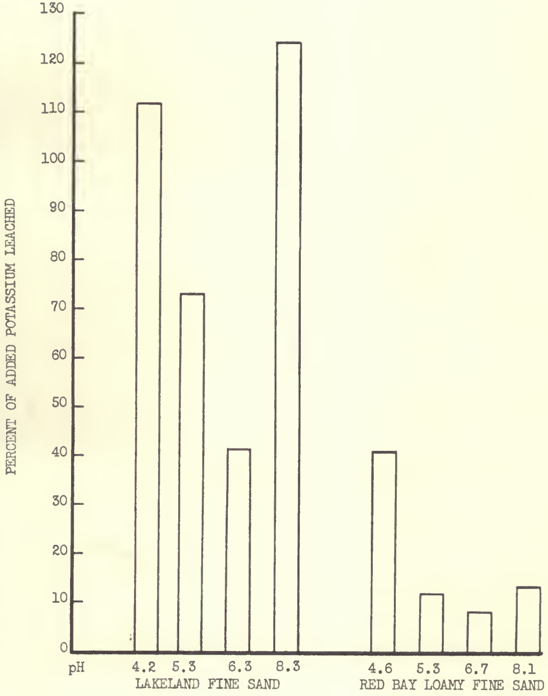

Figure 13--Percent of added potassium, as KCl, that leached from Lakeland and Red Bay soils in the laboratory with varying pH levels.

or magnesium than of hydrogen or aluminum from the soil exchange complex, and b) an increase in effective exchange capacity of the soils with increase in pH, due to the pH-dependent charges. Thomas and Coleman reported (63) that clay minerals have pH-dependent charges due to the ionization of the hydrogen ions from SiOH groups around the edges of crystals. Such charges do not develop below about pH 6, but may be of considerable importance in soils with higher pH values. Furthermore, the cation exchange associated with soil organic matter is probably of a pH-dependent nature. The liming of acid soils to near neutrality may have real practical significance as a means of increasing the base exchange capacity of sandy soils and thus reduce the loss of cations by leaching.

In Lakeland fine sand, a soil pH of about 6.5 appears to be the most favorable pH level for the retention of applied potassium salts. Although the C.E.C. of the soil tends to increase with increasing pH, the mass action effect of calcium apparently dominates the exchange reactions at the higher pH levels (pH 6.5 and above). Therefore, under normal field conditions, a liming practice to maintain the pH of the soil from 6.0 to 6.5 should result in maximum retention of applied potassium salts on Lakeland fine sand. On the Red Bay soil, however, the pH of the soil would not affect the retention of applied potassium except at abnormally low or very high pH levels.

SUMMARY AND CONCLUSION

A series of experiments were conducted in large lysimeters, in the greenhouse and in the laboratory to study certain factors related to leaching of potassium from mineral soil. The following variables were investigated and their relationships to potassium leaching discussed; soil cover, rates and methods of application of potassium fertilizers, leaching intensity, particle size and water solubility of potassium materials, and soil reaction.

Crops growing on the soil reduced the leaching losses of potassium in outdoor and greenhouse lysimeters. This reduction in leaching losses of potassium by crops was affected through a reduction in the amount of gravitational water passing through the soil and by the absorption of fertilizer potassium into the plant tissues. The volume of water leached through a fallow soil with a total of 62.22 inches of rainfall between November 11 and September 30 was 43.74 inches or 70.2 percent. Water loss from a combined oats and millet crop during the same period was 22.22 inches or 35.6 percent of the rainfall. The total loss of potassium from a fallow soil that received 480 pounds of K_2O per acre in two applications was 928.88 me., or equivalent to 39.1 percent of the amount applied to the soil. In contrast, the leaching loss from plots planted to oats and then millet was 56.12 me., or 4.1 percent of the amount applied to the soil. This represented a 89.5 percent reduction in leaching loss of potassium from the oats and millet plot, when compared with losses from the fallow soil.

The type of crop or root systems of crops greatly affected the leaching of potassium in the lysimeter and greenhouse experiments. The combined oat and millet crops reduced the leaching of potassium from an application of 480 pounds of K_2O per acre by 46.3 percent when compared with potassium leaching from the same rate of KCl on cabbage plus sweet potato crops.

When a uniform volume of water was leached through Lakeland sand in greenhouse pots planted to millet, radishes or left fallow, the potassium content of the leachings was 20, 57, and 118 mg., respectively, from the three cropping systems. The millet crop affected a 65 percent reduction in leaching losses of potassium, when compared with that lost from soils planted to radishes.

Millet and radish crops significantly reduced the amounts of potassium leached from a topdressed application of KCl on Lakeland fine sand. Less than 10 percent of an application equivalent to 100 pounds of K_2O per acre leached from the two crops in 3 1/2 or 7 inches of leachates. However, potassium losses were 88.6 and 164.8 percent of the 100 pounds applied to fallow soils given similar leaching treatments.

Potassium losses from an Arredondo fine sand in large lysimeters increased with each increment of KCl added to cropped and fallow soils. The amounts of potassium leached from fallow plots with total applications of 120, 240, and 480 pounds of K_2O per acre were 160.12, 283.07, and 928.29 me., respectively, for the period between November 11 and September 30.

Potassium leaching losses were greater from band placement of KCl than from a broadcast application on sweet potatoes. Potassium losses were 201.33 me. from band placement and 89.91 me. from broadcast placement. This represented a 200 percent greater loss of potassium from the band placement than from the broadcast method.

The anion associated with potassium significantly influenced the leaching of potassium from various fertilizer materials. Potassium leaching losses from 7 potassium materials were in the following order: KNO_3 > KCl > K_2SO_4 > KH_2PO_4 > KPO_3 (99.7 percent water soluble) > KPO_3 (13.7 percent water soluble) > K_2CO_3. The percent of applied potassium that leached from these sources ranged from 2.3 for K_2CO_3 to to 15.9 for KNO_3. Leaching losses of potassium were significantly higher from KNO_3 than from the other potassium materials. This was probably the result of large amounts of nitrate ions in the soil at the time of the first leaching.

The relative retention of the various anions in soils significantly affected the leaching losses of potassium. Chlorides appearing in the leachates were of the same magnitude as those applied by the potassium treatments. It was noted in all experiments that chlorides leached very rapidly from fallow or cropped soils. Nitrate-nitrogen leached very readily from the fallow soils, however, its rate of leaching was greatly reduced under crop growth. The sulfate anion was retained more strongly in the soils than the chloride or nitrate anions, although most of the added sulfate was removed in the first 6 to 8 inches of water leaching through the soil. Only traces of phosphorus were found in the leachates from any treatment.

Water solubility did not significantly affect the leaching of potassium from the soil. The percent of potassium leaching from an application equivalent to 200 pounds of K_2O per acre was 2.53 from KPO_3 (13.7 percent water soluble) and 2.83 percent from KPO_3 (99.7 percent water soluble). The losses from potassium phosphate sources were relatively low regardless of the water solubility of the material.

Increasing particle size significantly increased the leaching of potassium from a completely water soluble KCl. An increase of over 100 percent in potassium leaching resulted when the particle size of KCl was increased from -6+14 to -3/8+4 mesh. However, the effect of particle size of slightly soluble KPO_3 and $K_2CaP_2O_7$ on the leaching of potassium was not significant.

Soil reaction significantly influenced the amounts of potassium retained in Lakeland fine sand in a laboratory study. The average leaching losses of potassium at pH 4.2 were 1 3/4 times greater than at pH 5.3 and 2 3/4 times greater than at pH 6.3. When the pH was raised to 8.3, however, leaching losses were 3 times greater than the loss at pH 6.3. The amounts of potassium lost from a Red Bay soil were relatively small, even at relatively low pH levels; however, the influence of pH on potassium losses from this soil was similar to that observed with Lakeland fine sand. The reduction in potassium losses in soils limed to near neutrality is probably due to, 1) an easier substitution of potassium for calcium than for hydrogen or aluminum on the exchange complex, and 2) to an increase in the effective exchange capacity of the soil.

It is recognized that leaching data from greenhouse and laboratory experiments may not accurately predict what will happen under field conditions. Under field conditions, leaching losses are dependent upon cultural and fertilizer practices, intensity and distribution of rainfall, and moisture characteristics of the soil. Since these conditions can never be exactly duplicated in greenhouse or laboratory studies, the results obtained therein indicate only relative leaching rates and must be interpreted with a great deal of care. However, it is believed that results of this study may be of value in recognizing certain conditions that may result in increased losses of potassium by leaching and suggest methods of correcting those conditions.

Data obtained from these experiments indicate that the following practices would be advantageous for the conservation of potassium in Florida soils:

1. Maintain the soil pH from 6.0 to 6.5 through proper liming practices.
2. Use potassium materials such as potassium carbonate and potassium metaphosphate on sandy soils, where soil pH is not of primary importance.

3. Apply relatively small rates of potassium salts at any one application on sandy soils. For annual crops that require large amounts of potassium, apply the potassium in split applications with one-half at planting and one-half after the crops become established.
4. When large amounts of potassium salts are added in single applications, apply as broadcast rather than band placement.
5. Maintain a cover crop on the soil whenever possible.

APPENDIX

Table 20--Milliequivalents of ions leached through Arredondo fine sand receiving a band application of 100 pounds of KCl per acre to each of two crops.

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Winter crop (cabbage)				
1	46.9	0.91	0.84	62.61	6.90	100.46	31.82
2	46.6	0.90	0.83	83.42	12.64	48.58	42.16
3	57.9	1.12	1.33	128.25	26.18	41.34	65.47
4	47.3	0.92	0.79	113.50	20.61	89.16	85.58
5	67.0	1.30	0.94	268.00	50.67	246.84	151.53
6	62.5	1.21	1.28	450.00	116.11	508.73	169.92
7	56.0	1.09	0.72	263.00	108.18	412.63	101.32
8	67.0	1.30	0.69	257.95	82.61	361.66	45.46
9	24.2	0.50	0.20	85.91	21.88	118.88	5.47
10	37.9	0.75	0.31	134.55	43.62	194.84	Tr.
11	52.2	1.01	0.35	190.53	70.80	232.57	Tr.
12	56.4	1.09	0.46	188.94	60.27	251.29	Tr.
13	65.5	1.27	0.34	88.43	43.07	66.41	Tr.
14	53.7	1.04	0.36	24.17	6.63	23.01	Tr.
15	45.4	0.88	0.30	15.89	5.60	5.83	Tr.
16	50.7	0.98	0.41	12.68	6.26	14.46	Tr.
17	46.6	0.90	0.31	10.72	4.98	3.33	Tr.
18	31.4	0.61	0.26	3.46	3.35	3.58	Tr.
19	---	---	---	---	---	---	---
20	70.0	1.36	0.72	4.90	5.18	9.00	Tr.
Total	985.2	19.13	11.44	2,387.11	695.54	2,732.62	698.43

Table 20--(continued)

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Summer crop (sweet potatoes)				
21	65.1	1.26	0.57	48.15	10.17	18.59	Tr.
22	51.9	1.01	0.37	33.75	8.10	32.61	Tr.
23	51.9	1.01	0.53	203.95	37.54	211.22	58.69
24	69.6	1.35	1.32	400.20	105.84	375.69	125.93
25	58.3	1.13	2.06	392.90	98.25	390.45	92.30
26	54.5	1.06	1.59	335.18	107.52	446.72	86.28
27	40.5	0.79	1.43	166.66	38.62	182.18	27.48
28	48.1	0.93	1.60	141.90	34.01	136.00	8.18
29	39.0	0.76	1.00	127.34	18.91	138.67	Tr.
30	22.7	0.44	1.02	86.26	10.08	107.29	Tr.
31	---	---	---	---	---	---	---
32	---	---	---	---	---	---	---
33	48.1	0.93	0.62	131.56	13.84	140.81	Tr.
34	---	---	---	---	---	---	---
35	40.0	0.77	0.36	74.80	4.27	74.26	Tr.
36	---	---	---	---	---	---	---
37	---	---	---	---	---	---	---
38	61.7	1.20	1.58	28.38	0.51	4.41	Tr.
39	70.0	1.36	0.90	36.75	0.29	8.00	Tr.
Total	721.5	14.01	14.95	2,207.78	487.95	2,266.90	398.86
Total	1,706.7	33.14	26.39	4,594.89	1,183.89	4,999.52	1,097.29

Table 21--Milliequivalents of ions leached through Arredondo fine sand receiving a band application of 400 pounds of KCl per acre to each of two crops.

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Winter crop (cabbage)				
1	50.0	0.97	0.64	58.25	9.04	111.38	45.23
2	45.4	0.88	0.81	77.18	15.68	55.11	41.07
3	59.0	1.14	1.21	137.18	37.34	58.13	66.72
4	46.6	0.90	0.90	202.71	44.82	123.77	162.95
5	65.5	1.27	1.09	533.83	137.30	353.56	399.97
6	65.5	1.27	1.26	632.08	165.83	439.61	488.85
7	54.1	1.05	0.69	357.06	104.51	363.33	232.48
8	68.5	1.33	0.70	321.95	98.54	352.14	154.92
9	23.9	0.46	0.19	102.77	34.38	129.01	76.22
10	39.0	0.76	0.56	157.95	56.10	210.52	Tr.
11	48.1	0.93	0.25	190.00	69.20	259.64	Tr.
12	59.0	1.14	1.27	197.65	38.80	252.76	Tr.
13	65.1	1.26	0.43	97.65	29.44	85.52	Tr.
14	57.2	1.11	0.94	20.02	7.05	22.87	Tr.
15	45.8	0.89	0.47	11.45	5.65	11.77	Tr.
16	52.6	1.02	0.86	13.15	6.49	15.02	Tr.
17	50.0	0.97	0.26	4.50	3.29	2.14	Tr.
18	32.6	0.63	0.27	2.94	2.15	3.58	Tr.
19	---	---	---	---	---	---	---
20	69.3	1.34	0.89	6.24	7.41	9.00	Tr.
Total	997.2	19.35	13.69	3,124.56	873.02	2,857.86	1,608.41

Table 21--(continued)

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Summer crop (sweet potatoes)				
21	60.2	1.17	0.52	22.60	4.46	12.89	Tr.
22	50.3	0.98	0.95	57.85	14.48	64.65	Tr.
23	54.5	1.06	1.92	190.50	39.42	94.95	125.52
24	65.9	1.28	17.66	450.75	94.80	293.61	342.80
25	57.9	1.12	25.77	565.98	114.23	364.63	366.66
26	56.0	1.09	39.67	519.96	134.41	479.81	341.96
27	40.0	0.78	27.62	226.40	46.03	232.48	99.51
28	46.2	0.90	28.12	180.18	36.08	189.35	21.52
29	30.7	0.60	14.13	110.52	21.70	138.09	Tr.
30	16.8	0.33	12.25	65.52	10.08	83.72	Tr.
31	---	---	---	---	---	---	---
32	---	---	---	---	---	---	---
33	---	---	---	---	---	---	---
34	59.0	1.14	20.52	67.26	2.42	96.05	Tr.
35	---	---	---	---	---	---	---
36	---	---	---	---	---	---	---
37	8.0	0.16	3.97	8.24	1.05	10.28	Tr.
38	48.4	0.94	3.29	6.78	0.20	6.91	Tr.
39	68.9	1.34	4.93	11.03	0.57	11.81	Tr.
Total	663.8	12.89	201.32	2,483.57	519.93	2,079.23	1,297.97
Total	1,661.0	32.24	215.01	5,608.13	1,392.95	4,936.99	2,906.38

Table 22--Milliequivalents of ions leached through Arredondo fine sand receiving a broadcast application of 200 pounds of KCl per acre to each of two crops.

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Winter crop (cabbage)				
1	50.3	0.98	0.65	51.56	7.44	112.06	34.13
2	46.6	0.90	0.72	76.19	12.64	87.84	84.32
3	59.0	1.14	1.06	153.40	37.34	64.87	104.81
4	52.2	1.01	0.88	148.77	29.61	111.81	104.81
5	66.2	1.28	1.10	410.44	87.07	340.32	237.02
6	65.5	1.27	1.42	586.23	175.52	639.77	311.09
7	57.5	1.12	0.38	253.00	77.99	310.38	100.78
8	69.3	1.34	0.57	232.16	74.05	267.19	78.36
9	25.3	0.49	0.17	74.64	20.80	78.04	5.72
10	41.3	0.80	0.34	111.51	33.95	146.26	Tr.
11	53.7	1.04	0.36	150.36	48.56	172.54	Tr.
12	58.3	1.13	0.39	201.14	62.30	273.07	Tr.
13	66.2	1.28	0.44	82.75	24.49	80.35	Tr.
14	54.0	1.09	0.29	19.60	6.90	18.39	Tr.
15	46.6	0.90	0.31	11.65	5.75	8.65	Tr.
16	52.2	1.01	0.43	13.05	6.44	7.45	Tr.
17	54.1	1.05	0.28	10.55	2.67	2.32	Tr.
18	32.9	0.64	0.17	5.60	4.32	3.76	Tr.
19	---	---	---	---	---	---	---
20	71.2	1.38	0.47	6.41	4.69	13.22	Tr.
Total	1,024.4	19.89	10.43	2,599.01	727.53	2,738.29	1,003.45

Table 22--(continued)

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Summer crop (sweet potatoes)				
21	62.8	1.22	0.45	26.40	3.10	13.45	Tr.
22	48.4	0.94	0.50	46.95	9.15	41.47	Tr.
23	54.1	1.05	0.55	182.60	35.58	128.24	61.18
24	67.4	1.31	1.76	454.30	108.04	363.81	213.41
25	59.8	1.16	4.74	460.46	100.77	400.50	243.44
26	56.4	1.09	6.26	385.78	105.70	462.29	102.59
27	42.4	0.82	4.40	169.60	34.85	181.36	38.63
28	45.3	0.88	5.54	163.14	35.91	156.36	12.12
29	44.0	0.85	3.17	100.60	25.98	179.93	Tr.
30	2.16	0.42	1.65	68.04	19.35	76.80	Tr.
31	---	---	---	---	---	---	---
32	---	---	---	---	---	---	---
33	46.9	0.91	5.28	138.59	20.43	188.20	Tr.
34	---	---	---	---	---	---	---
35	3.94	0.76	5.80	82.74	5.51	92.83	Tr.
36	---	---	---	---	---	---	---
37	---	---	---	---	---	---	---
38	51.1	0.99	1.67	19.17	0.42	8.75	Tr.
39	70.8	1.37	3.08	20.53	4.08	10.11	Tr.
Total	716.4	13.91	44.85	2,318.91	508.87	2,304.10	671.37
Total	1,740.8	33.80	55.28	4,917.92	1,236.40	5,042.39	1,674.82

Table 23--Milliequivalents of ions leached through Arredondo fine sand receiving a broadcast application of 400 pounds of KCl per acre to each of two fallow periods.

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Winter crop (fallow)				
1	48.4	0.94	0.74	56.39	8.75	103.67	54.73
2	55.6	1.08	0.86	104.81	20.57	101.63	50.30
3	66.2	1.28	1.19	162.85	54.42	106.24	104.81
4	49.6	0.96	0.82	252.96	47.70	207.90	168.24
5	67.4	1.31	1.47	556.05	141.28	381.14	426.82
6	62.1	1.20	1.03	291.87	76.57	505.45	444.41
7	71.9	1.39	0.74	424.21	118.20	513.37	163.77
8	68.5	1.33	0.88	321.95	104.17	387.17	94.04
9	58.3	1.13	0.60	212.80	71.88	195.64	11.44
10	58.7	1.14	0.75	173.17	72.38	316.85	Tr.
11	74.9	1.45	1.07	273.39	101.59	320.87	Tr.
12	56.0	1.09	2.01	210.00	64.44	302.28	Tr.
13	68.1	1.32	3.14	163.44	44.78	186.71	Tr.
14	62.5	1.21	3.93	96.88	20.55	100.00	Tr.
15	50.7	0.98	2.98	76.05	16.67	57.92	Tr.
16	52.2	1.01	3.15	44.37	6.44	36.53	Tr.
17	54.9	1.07	1.60	24.43	5.87	15.68	Tr.
18	70.8	1.37	2.28	28.32	9.31	20.22	Tr.
19	73.5	1.43	2.52	30.51	5.44	29.39	Tr.
20	34.4	0.67	1.55	18.58	7.35	17.19	Tr.
Total	1,204.7	23.37	33.31	3,523.03	998.36	3,906.06	1,518.60

Table 23--(continued)

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Summer crop (fallow)				
21	59.8	1.16	5.29	53.20	9.34	55.51	Tr.
22	49.6	0.96	7.61	62.00	13.46	81.45	Tr.
23	50.3	0.98	26.89	254.75	45.48	178.14	147.89
24	69.3	1.34	97.48	547.80	99.69	347.07	407.50
25	59.8	1.16	97.73	532.22	90.94	376.59	378.69
26	53.7	1.04	44.36	393.09	116.53	381.88	255.05
27	53.0	1.03	37.55	252.28	54.02	292.14	119.87
28	65.5	1.27	42.55	213.86	46.30	221.68	34.61
29	71.9	1.39	41.56	172.56	39.00	195.08	Tr.
30	60.6	1.18	73.31	269.07	54.29	393.74	Tr.
31	41.6	0.81	51.07	185.10	37.27	340.98	Tr.
32	73.9	1.43	56.70	235.02	32.20	368.30	Tr.
33	43.1	0.84	31.97	117.88	12.40	176.64	Tr.
34	---	---	---	---	---	---	---
35	57.9	1.12	48.42	176.89	25.23	288.56	Tr.
36	59.0	1.14	50.85	198.54	45.59	308.36	Tr.
37	50.0	0.97	47.95	132.00	34.52	130.66	Tr.
38	77.6	1.15	60.83	108.65	34.52	130.52	Tr.
39	73.8	1.43	72.86	89.30	21.23	120.14	Tr.
Total	1,070.2	20.78	894.98	3,994.21	804.92	4,422.44	1,343.61
Total	2,274.9	44.15	928.29	7,517.24	1,803.28	8,328.50	2,862.21

Table 24--Milliequivalents of ions leached through Arredondo fine sand receiving a broadcast application of 200 pounds of KCl per acre to each of two fallow periods.

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Winter crop (fallow)				
1	48.8	0.95	0.75	53.68	10.03	94.08	44.15
2	55.3	1.07	0.85	95.95	21.82	64.75	75.04
3	65.1	1.26	1.17	152.99	60.47	159.89	147.23
4	47.7	0.93	0.79	290.97	83.52	245.22	183.40
5	62.5	1.21	0.88	346.88	95.56	321.30	197.89
6	62.5	1.21	1.44	615.63	179.30	292.74	155.49
7	71.9	1.39	0.59	269.63	109.34	585.24	81.31
8	68.5	1.33	0.46	208.93	50.68	334.54	46.48
9	59.0	1.14	0.30	123.90	43.65	175.24	13.34
10	59.0	1.14	0.39	147.50	63.05	291.51	Tr.
11	74.9	1.45	0.61	295.86	80.05	171.13	Tr.
12	55.6	1.08	0.91	175.14	54.84	247.72	Tr.
13	68.5	1.33	1.12	137.00	36.60	156.51	Tr.
14	52.6	1.01	0.94	78.90	28.10	75.11	Tr.
15	52.2	1.01	0.93	60.03	17.16	51.44	Tr.
16	51.5	1.00	0.92	33.48	6.35	25.74	Tr.
17	54.9	1.07	0.37	25.26	8.12	15.68	Tr.
18	71.5	1.39	0.73	24.31	12.93	17.36	Tr.
19	73.5	1.43	0.61	29.40	7.86	29.39	Tr.
20	32.9	0.64	0.34	18.43	6.49	16.44	Tr.
Total	1,188.4	23.05	15.10	3,183.87	975.91	3,371.03	944.33

Table 24--(continued)

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Summer crop (fallow)				
21	62.1	1.20	3.97	51.25	11.74	53.21	Tr.
22	50.0	0.97	2.74	61.50	14.39	73.54	Tr.
23	50.3	0.98	10.29	158.95	39.28	129.29	56.88
24	69.3	1.34	21.27	343.40	70.63	308.76	156.73
25	60.6	1.18	20.15	420.57	126.03	381.63	109.64
26	54.1	1.05	11.51	329.90	101.39	351.51	97.89
27	51.1	0.99	7.66	221.78	48.73	218.91	57.78
28	62.8	1.22	9.16	211.95	44.40	212.54	18.17
29	71.9	1.39	14.12	233.68	59.10	243.34	Tr.
30	58.7	1.14	21.44	260.63	55.97	341.16	Tr.
31	37.9	0.74	21.99	195.95	61.06	292.25	Tr.
32	74.7	1.45	17.58	276.39	71.23	372.29	Tr.
33	42.8	0.83	11.49	137.65	33.07	175.41	Tr.
34	---	---	---	---	---	---	---
35	59.0	1.14	17.96	230.40	45.59	294.04	Tr.
36	54.9	1.07	15.75	220.43	48.89	273.60	Tr.
37	48.4	0.94	17.23	130.68	40.18	126.48	Tr.
38	78.5	1.52	28.39	140.50	36.14	140.12	Tr.
39	71.9	1.39	24.27	94.19	21.87	100.62	Tr.
Total	1,058.8	20.56	267.97	3,711.80	929.69	4,088.70	497.69
Total	2,247.2	43.61	283.07	6,895.67	1,905.60	7,459.73	1,442.02

Table 25--Milliequivalents of ions leached through Arredondo fine sand receiving a broadcast application of 400 pounds of KCl per acre to each of two crops.

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Winter crop (oats)				
1	50.0	0.97	0.77	75.00	13.56	167.43	67.85
2	46.9	0.91	0.84	100.84	33.54	115.20	53.04
3	46.9	0.91	0.96	159.46	57.83	157.39	116.68
4	36.7	0.71	0.84	262.41	72.40	198.10	166.01
5	61.7	1.20	1.58	447.33	136.94	301.33	348.86
6	59.8	1.11	1.68	439.53	151.40	338.16	365.16
7	18.1	0.35	0.34	132.13	48.36	129.23	85.96
8	1.9	0.04	0.05	13.49	5.08	13.57	81.64
9	---	---	---	---	---	---	---
10	---	---	---	---	---	---	---
11	---	---	---	---	---	---	---
12	---	---	---	---	---	---	---
13	67.8	1.32	0.45	240.69	61.30	142.81	109.28
14	51.9	1.01	0.35	108.99	27.73	34.84	Tr.
15	30.7	0.60	0.25	47.59	7.57	13.15	Tr.
16	44.3	0.86	0.36	85.10	23.67	11.39	Tr.
17	24.6	0.48	0.16	24.36	6.07	5.97	Tr.
18	---	---	---	---	---	---	---
19	---	---	---	---	---	---	---
20	---	---	---	---	---	---	---
Total	541.3	10.50	8.63	2,136.92	645.45	1,628.57	1,394.48

Table 25--(continued)

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Summer crop (millet)				
21	45.8	0.89	1.10	27.95	3.39	16.71	Tr.
22	45.8	0.89	1.69	125.70	21.08	67.37	Tr.
23	53.7	1.04	3.93	293.20	69.30	142.63	218.61
24	69.6	1.35	7.73	598.55	137.31	357.80	425.01
25	60.6	1.18	9.70	482.81	175.18	403.18	108.92
26	53.4	1.04	5.54	416.52	128.17	437.70	217.39
27	23.5	0.43	2.02	114.21	22.41	111.08	53.15
28	---	---	---	---	---	---	---
29	---	---	---	---	---	---	---
30	8.7	0.17	0.71	42.48	8.87	35.66	13.78
31	---	---	---	---	---	----	---
32	---	---	---	---	---	---	---
33	---	---	---	---	---	---	---
34	---	---	---	---	---	---	---
35	53.4	1.04	7.85	43.52	1.32	9.15	Tr.
36	---	---	---	---	---	---	---
37	17.6	0.34	0.82	4.77	1.16	1.26	Tr.
38	75.7	1.47	3.41	21.96	4.36	2.71	Tr.
39	64.3	1.25	2.99	17.36	10.57	15.61	Tr.
Total	572.7	11.12	47.49	2,188.83	583.12	1,600.86	1,050.64
Total	1,114.0	21.62	56.12	4,325.75	1,228.57	3,229.43	2,445.12

Table 26--Milliequivalents of ions leached through Arredondo fine sand receiving a broadcast application of 100 pounds of KCl per acre to each of two crops.

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Winter crop (cabbage)				
1	50.0	0.97	0.90	76.75	10.28	157.44	22.62
2	46.2	0.90	1.06	103.95	18.23	118.75	31.35
3	56.4	1.09	1.15	203.04	61.66	181.21	76.53
4	48.4	0.94	1.05	263.78	63.66	248.81	109.46
5	65.9	1.28	1.10	322.91	74.21	321.84	163.95
6	62.1	1.20	1.35	304.29	94.95	319.24	252.81
7	57.5	1.12	0.59	232.88	77.99	259.60	78.03
8	65.1	1.26	0.53	224.60	74.92	264.94	44.17
9	25.0	0.49	0.20	55.00	16.44	39.98	13.34
10	37.1	0.72	0.19	64.93	24.40	63.05	Tr.
11	49.2	0.95	0.18	98.40	26.29	108.90	Tr.
12	54.1	1.05	0.19	124.43	35.58	143.69	Tr.
13	66.6	1.29	0.34	109.89	35.58	106.51	Tr.
14	51.9	1.01	0.27	23.55	4.05	20.75	Tr.
15	46.2	0.90	0.24	16.17	5.70	13.85	Tr.
16	49.6	0.96	0.33	12.40	6.12	6.38	Tr.
17	42.8	0.83	0.22	14.55	6.33	3.06	Tr.
18	29.9	0.58	0.15	8.08	5.41	0.64	Tr.
19	---	---	---	---	---	---	---
20	62.8	1.22	0.90	9.42	6.71	13.45	Tr.
Total	966.8	18.76	10.94	2,269.02	648.51	2,429.09	792.26

Table 26--(continued)

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Summer crop (sweet potatoes)				
21	62.8	1.22	0.32	35.80	1.55	22.42	Tr.
22	49.6	0.96	0.43	52.10	11.42	47.45	Tr.
23	50.0	0.97	0.61	237.50	49.73	234.19	67.85
24	70.0	1.36	1.15	423.50	100.70	417.83	126.65
25	60.6	1.18	1.36	390.87	102.12	381.63	82.23
26	53.4	1.04	2.40	264.60	81.21	327.90	48.31
27	43.5	0.84	1.40	165.30	28.25	169.58	19.68
28	70.0	1.36	1.36	236.35	42.00	236.91	5.21
29	49.6	0.96	1.45	135.16	22.01	145.20	Tr.
30	31.8	0.62	0.63	100.17	17.25	113.07	Tr.
31	---	---	---	---	---	---	---
32	73.9	1.43	0.53	193.14	66.21	495.99	Tr.
33	41.6	0.81	0.42	199.68	24.96	217.42	Tr.
34	---	---	---	---	---	---	----
35	51.9	1.01	0.67	153.57	22.61	184.54	Tr.
36	---	---	---	---	---	---	---
37	2.8	0.05	0.12	10.92	2.33	8.64	Tr.
38	73.8	1.43	1.51	92.25	12.13	61.13	Tr.
39	71.9	1.39	2.35	78.37	14.78	61.60	Tr.
Total	857.0	16.64	16.71	2,769.38	599.26	3,125.50	349.93
Total	1,823.8	35.40	27.65	5,038.40	1,247.77	5,553.59	1,142.29

Table 27--Milliequivalents of ions leached through Arredondo fine sand receiving a broadcast application of 100 pounds of KCl per acre to each of two crops.

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Winter crop (oats)				
1	51.9	1.03	0.93	86.42	11.94	126.74	23.48
2	45.8	0.89	0.82	89.31	15.82	93.53	41.43
3	50.0	0.97	0.90	140.75	43.98	137.09	79.16
4	40.9	0.79	0.68	204.50	39.33	199.75	157.25
5	62.5	1.21	0.88	368.75	82.20	373.07	155.49
6	58.7	1.14	1.25	396.23	115.80	502.94	212.41
7	18.9	0.37	0.19	105.84	83.16	145.74	21.37
8	9.8	0.19	0.08	47.04	13.29	58.48	110.82
9	---	---	---	---	---	---	---
10	---	---	---	---	---	---	---
11	---	---	---	---	---	---	---
12	41.6	0.81	0.21	112.32	40.65	84.95	Tr.
13	52.2	1.03	0.19	109.62	23.60	54.54	Tr.
14	49.6	0.96	0.41	66.96	6.12	33.29	Tr.
15	34.1	0.66	0.17	35.81	8.41	7.30	Tr.
16	43.5	0.84	0.45	28.28	7.15	6.21	Tr.
17	26.5	0.51	0.18	9.28	5.23	1.89	Tr.
18	---	---	---	---	---	---	---
19	---	---	---	---	---	---	---
20	8.8	0.17	0.09	2.03	2.38	0.63	Tr.
Total	594.8	11.54	7.02	1,803.14	449.06	1,848.15	Tr.

Table 27--(continued)

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Summer crop (millet)				
21	70.4	1.37	1.01	76.75	15.04	50.27	Tr.
22	51.9	1.01	0.98	124.55	32.00	111.17	Tr.
23	50.3	0.98	0.62	249.25	55.82	224.10	68.26
24	70.8	1.37	1.16	484.25	101.85	422.61	80.06
25	59.0	1.14	1.72	368.75	80.51	395.14	93.41
26	52.6	1.02	1.35	233.55	71.78	274.91	35.69
27	30.3	0.59	0.98	98.93	16.44	85.67	13.71
28	---	---	---	---	---	---	---
29	---	---	---	---	---	---	---
30	12.2	0.24	0.06	39.84	7.32	35.71	Tr.
31	---	---	---	---	---	---	---
32	---	---	---	---	---	---	---
33	---	---	---	---	---	---	---
34	---	---	---	---	---	---	---
35	63.6	1.23	1.14	16.85	1.57	11.81	Tr.
36	---	---	---	---	---	---	---
37	30.3	0.59	0.16	69.70	0.75	5.19	Tr.
38	75.7	1.47	0.58	26.12	1.87	6.48	Tr.
39	67.4	1.31	0.86	35.39	1.66	25.99	Tr.
Total	634.5	12.32	10.62	1,823.93	386.61	1,649.05	295.49
Total	1,229.3	23.86	17.64	3,627.07	885.67	3,497.20	1,096.90

Table 28--Milliequivalents of ions leached through Arredondo fine sand receiving a broadcast application of 100 pounds of KCl per acre to each of two fallow periods.

Leachings			Milliequivalents of ions leached				
Number	Liter	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Winter crop (fallow)				
1	50.0	0.97	1.02	80.00	10.28	111.38	22.62
2	50.3	0.98	1.16	94.82	18.61	102.72	56.88
3	61.3	1.19	0.94	157.24	50.39	162.82	83.18
4	47.7	0.93	0.98	274.28	72.93	300.29	86.30
5	65.1	1.26	1.45	361.31	99.54	409.96	132.51
6	62.1	1.20	1.59	332.24	89.33	391.07	168.54
7	71.2	1.38	1.02	313.28	96.57	424.99	64.41
8	69.3	1.34	0.99	246.02	74.05	282.04	31.35
9	54.1	1.05	0.55	151.48	48.92	191.59	12.24
10	57.9	1.12	0.47	170.81	61.87	141.39	Tr.
11	74.9	1.45	0.77	273.39	86.19	265.25	Tr.
12	54.1	1.05	0.44	187.46	66.71	265.76	Tr.
13	66.2	1.28	0.54	158.88	54.42	204.19	Tr.
14	51.1	0.99	0.34	89.43	33.60	104.35	Tr.
15	51.9	1.01	0.53	77.85	12.06	68.19	Tr.
16	50.3	0.98	0.72	42.76	16.54	43.10	Tr.
17	54.9	1.07	0.20	31.84	10.83	20.38	Tr.
18	68.1	1.32	0.45	27.24	10.08	1.46	Tr.
19	73.5	1.43	0.49	29.40	12.08	18.89	Tr.
20	34.8	0.68	0.23	22.62	6.83	20.87	Tr.
Total	1,168.8	22.67	14.88	3,122.35	936.83	3,530.79	658.03

Table 28 --(continued)

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Summer crop (fallow)				
21	64.3	1.25	0.66	55.95	15.86	55.09	Tr.
22	46.9	0.91	2.47	62.00	17.35	77.02	Tr.
23	50.0	0.97	1.38	137.00	29.18	132.80	33.92
24	68.9	1.34	4.90	355.85	94.01	336.49	202.57
25	59.8	1.16	8.47	415.01	112.07	400.50	108.20
26	54.1	1.05	6.20	338.13	129.85	486.71	85.65
27	53.0	1.03	4.91	257.05	57.51	292.14	47.95
28	63.2	1.23	5.82	205.40	41.04	194.94	10.13
29	71.2	1.38	6.55	163.76	31.61	193.18	Tr.
30	61.7	1.20	13.38	253.90	62.89	307.50	Tr.
31	40.5	0.79	10.88	214.86	43.62	280.49	Tr.
32	74.3	1.44	6.98	290.14	48.86	370.29	Tr.
33	42.0	0.81	7.63	135.03	18.30	179.93	Tr.
34	---	---	---	---	---	---	---
35	63.6	1.23	12.69	235.32	52.28	332.40	Tr.
36	57.2	1.11	10.83	242.24	47.02	332.45	Tr.
37	48.8	0.95	11.63	151.49	40.18	131.32	Tr.
38	78.5	1.52	15.46	135.02	45.82	140.12	Tr.
39	73.1	1.42	14.40	98.69	24.64	104.39	Tr.
Total	1,075.8	20.89	145.24	3,757.44	912.09	4,347.76	488.42
Total	2,244.6	43.56	160.12	6,879.79	1,848.92	7,878.55	1,146.45

Table 29 --Milliequivalents of ions leached through Arredondo fine sand receiving a broadcast application of 200 pounds of KCl per acre to each of two crops.

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Winter crop (oats)				
1	52.2	1.01	1.20	86.92	12.02	127.46	35.42
2	46.2	0.90	1.18	90.09	18.23	87.09	73.14
3	46.6	0.90	1.07	124.19	45.97	68.54	52.70
4	41.3	0.80	0.90	121.84	23.43	97.90	84.06
5	60.9	1.18	1.40	313.68	87.61	297.42	206.57
6	60.9	1.18	2.03	426.30	127.66	434.83	330.56
7	8.5	0.16	0.36	118.40	37.26	123.90	50.21
8	0.8	0.02	0.02	3.08	0.99	1.72	0.54
9	---	---	---	---	---	---	---
10	---	---	---	---	---	---	---
11	---	---	---	---	---	---	---
12	---	---	---	---	---	---	---
13	41.6	0.81	0.21	83.20	10.26	20.79	Tr.
14	52.6	1.02	0.27	65.75	8.65	15.77	Tr.
15	33.7	0.65	0.23	32.02	8.31	4.81	Tr.
16	40.9	0.79	0.42	18.41	5.05	8.76	Tr.
17	22.7	0.44	0.12	4.43	2.80	1.62	Tr.
18	---	---	---	---	---	---	---
19	---	---	---	---	---	---	---
20	---	---	---	---	---	---	---
Total	518.9	10.07	9.41	1,488.31	388.24	1,290.61	833.20

Table 29--(continued)

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Summer crop (millet)				
21	31.4	0.61	1.11	41.15	7.74	8.97	Tr.
22	39.4	0.76	0.89	112.30	15.54	84.39	Tr.
23	54.1	1.05	1.58	279.45	53.36	208.58	134.59
24	66.6	1.29	1.50	494.50	101.28	285.31	225.90
25	60.2	1.17	2.71	429.53	82.14	403.18	177.00
26	53.4	1.04	1.77	248.31	81.21	279.10	60.38
27	32.2	0.62	0.94	101.43	19.33	84.14	14.57
28	---	---	---	---	---	---	---
29	---	---	---	---	---	---	---
30	13.2	0.26	0.30	35.97	5.90	23.56	Tr.
31	---	---	---	---	---	---	---
32	---	---	---	---	---	---	---
33	---	---	---	---	---	---	---
34	---	---	---	---	---	---	---
35	66.6	1.29	2.13	10.99	1.64	14.27	Tr.
36	---	---	---	---	---	---	---
37	10.6	0.21	0.27	2.44	4.36	1.51	Tr.
38	75.7	1.47	1.94	26.10	3.73	14.05	Tr.
39	70.4	1.37	1.80	21.83	3.47	13.07	Tr.
Total	573.7	11.14	16.94	1,804.00	379.70	1,420.14	627.01
Total	1,092.6	21.21	26.35	3,292.31	767.94	2,710.75	1,460.21

Table 30--Milliequivalents of ions leached through Arredondo fine sand receiving a band application of 200 pounds of KCl per acre to each of two crops.

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Winter crop (cabbage)				
1	50.3	0.98	0.90	90.04	13.65	135.75	56.88
2	46.6	0.90	0.95	124.19	16.09	113.13	73.77
3	58.7	1.14	1.35	184.03	41.98	150.88	119.48
4	49.2	0.95	0.94	277.98	64.31	210.77	155.78
5	66.6	1.29	1.11	429.57	95.80	397.54	225.90
6	62.1	1.20	1.43	422.28	108.73	443.39	308.98
7	59.0	1.14	0.75	306.80	72.75	371.55	120.09
8	61.4	1.31	0.86	259.49	72.02	315.69	45.73
9	23.8	0.46	0.16	82.11	23.48	101.96	10.77
10	35.6	0.69	0.24	115.70	35.12	192.17	Tr.
11	51.7	1.00	0.26	193.88	46.75	230.34	Tr.
12	53.7	1.04	0.44	163.79	39.73	197.84	Tr.
13	66.2	1.28	0.54	82.75	21.77	75.63	Tr.
14	53.0	1.03	0.27	18.55	6.53	21.92	Tr.
15	45.8	0.89	0.30	16.03	5.65	13.08	Tr.
16	51.9	1.01	0.35	12.98	6.40	9.63	Tr.
17	44.7	0.87	0.37	10.28	2.94	3.19	Tr.
18	29.1	0.56	0.30	10.19	3.83	6.23	Tr.
19	---	---	---	---	---	---	---
20	66.2	1.28	0.34	5.96	5.98	9.45	Tr.
Total	981.6	19.04	11.86	2,806.60	683.51	3,000.14	1,117.38

Table 30--(continued)

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Summer crop (sweet potatoes)				
21	67.0	1.30	0.58	24.55	4.96	19.14	Tr.
22	51.1	0.99	0.45	61.85	10.92	65.67	Tr.
23	48.8	0.95	0.75	241.80	44.12	198.61	99.33
24	68.9	1.34	2.18	491.60	122.90	389.62	233.70
25	59.0	1.14	3.32	409.46	116.40	352.17	173.47
26	54.1	1.05	3.27	278.62	73.82	332.20	85.65
27	45.4	0.88	2.74	186.82	35.45	214.59	51.34
28	57.5	1.12	3.82	207.00	27.89	224.16	Tr.
29	44.3	0.86	4.08	159.48	24.04	199.27	Tr.
30	14.7	0.29	1.47	60.49	14.99	76.83	Tr.
31	---	---	---	---	---	---	---
32	---	---	---	---	---	---	---
33	---	---	---	---	---	---	---
34	58.7	1.14	0.60	66.92	2.42	83.82	Tr.
35	---	---	---	---	---	---	---
36	---	---	---	---	---	---	---
37	10.2	0.20	0.13	7.14	0.67	4.23	Tr.
38	55.6	1.08	0.17	28.08	2.29	6.35	Tr.
39	68.1	1.32	0.87	22.48	2.80	9.72	Tr.
Total	703.5	13.66	24.43	2,246.29	483.67	2,076.38	694.83
Total	1,685.1	32.70	36.29	5,052.89	1,167.18	5,076.52	1,812.21

Table 31--Milliequivalents of ions leached through Arredondo fine sand receiving a broadcast application of 400 pounds of KCl per acre to each of two crops.

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Winter crop (cabbage)				
1	45.8	0.89	0.94	95.50	21.83	123.61	51.79
2	50.3	0.98	0.90	127.51	29.77	73.98	102.39
3	53.0	1.03	1.22	146.55	46.62	75.68	131.85
4	47.3	0.92	0.91	210.49	41.99	140.49	149.76
5	64.0	1.24	2.21	553.60	134.15	382.02	448.71
6	61.3	1.20	0.94	554.77	146.13	437.68	388.19
7	55.3	1.07	0.79	353.92	118.19	370.36	225.12
8	63.6	1.23	0.81	311.64	96.72	359.65	143.84
9	23.1	0.45	0.30	95.87	23.74	94.01	15.67
10	32.1	0.64	0.27	113.51	35.16	93.75	Tr.
11	43.5	0.84	0.22	108.75	35.76	213.69	Tr.
12	57.9	1.12	0.30	107.12	26.18	98.39	Tr.
13	62.5	1.21	0.42	34.38	7.71	54.44	Tr.
14	55.6	1.08	0.37	13.90	13.71	15.88	Tr.
15	43.9	0.85	0.36	10.98	5.42	8.15	Tr.
16	53.0	1.03	0.95	13.25	6.53	9.84	Tr.
17	40.5	0.79	0.41	5.67	2.66	5.21	Tr.
18	29.5	0.57	0.60	3.25	1.45	4.21	Tr.
19	---	---	---	---	---	---	---
20	63.2	1.23	0.65	1.58	10.39	11.73	Tr.
Total	946.2	18.36	13.54	2,862.24	804.11	2,472.77	1,657.32

Table 31--(continued)

Leachings			Milliequivalents of ions leached				
Number	Liters	Acre inch	K	Ca	Mg	NO_3-N	Cl
			Summer crop (sweet potatoes)				
21	64.7	1.26	0.56	22.95	3.72	15.71	Tr.
22	47.3	0.92	0.48	48.95	9.72	54.04	Tr.
23	51.1	0.99	1.05	273.65	62.59	188.27	69.34
24	66.6	1.29	9.20	586.10	131.39	359.50	421.75
25	57.2	1.11	19.90	474.76	112.84	341.43	310.48
26	54.1	1.05	14.25	359.23	96.50	351.51	171.30
27	42.4	0.82	9.54	201.82	46.01	200.41	86.30
28	53.7	1.04	11.65	214.80	29.13	200.44	16.24
29	37.1	0.72	7.76	125.22	17.99	125.56	Tr.
30	16.6	0.32	3.95	54.20	11.74	56.18	Tr.
31	---	---	---	---	---	---	---
32	---	---	---	---	---	---	---
33	---	---	---	---	---	---	---
34	54.9	1.07	6.18	14.55	2.26	22.73	Tr.
35	---	---	---	---	---	---	---
36	---	---	---	---	---	---	---
37	9.4	0.18	0.97	3.95	0.70	1.74	Tr.
38	67.4	1.31	3.62	15.50	3.32	7.70	Tr.
39	20.4	0.40	0.80	5.92	1.00	2.91	Tr.
Total	642.7	12.48	89.91	2,401.61	528.91	1,927.83	1,075.41
Total	1,588.9	30.84	103.45	5,263.85	1,333.02	4,500.60	2,732.73

Table 32--Cation exchange capacity, exchangeable bases, extractable phosphorus and pH of soil samples from 0 to 12 and 12 to 24 inches in large lysimeters.

Lysimeter No.	Soil (inches)	pH	Exchange capacity (me./100 g.)	Exchangeable bases (me./100 g.)			Extractable* phosphorus (lbs./A)
				Ca	Mg	K	P_2O_5
First sampling (10-2-58)							
1	0-12	6.0	2.12	1.824	0.354	0.043	13
	12-24	5.8	1.04	0.600	0.107	0.015	8
2	0-12	6.0	2.32	1.626	0.263	0.031	11
	12-24	6.1	1.51	0.600	0.107	0.015	10
3	0-12	6.1	2.93	1.824	0.288	0.031	14
	12-24	5.9	1.22	0.600	0.132	0.015	8
4	0-12	6.0	2.14	1.450	0.263	0.031	12
	12-24	5.8	1.03	0.476	0.132	0.015	9
5	0-12	6.1	2.35	1.450	0.263	0.031	12
	12-24	6.0	1.13	0.550	0.132	0.015	9
6	0-12	6.1	3.13	2.450	0.288	0.031	21
	12-24	5.9	1.04	0.750	0.107	0.015	11
7	0-12	6.1	2.42	2.276	0.263	0.033	21
	12-24	6.1	1.41	0.600	0.132	0.015	13
8	0-12	6.1	3.22	2.000	0.354	0.031	14
	12-24	6.0	1.24	0.600	0.189	0.020	11
9	0-12	6.1	2.15	2.000	0.354	0.031	13
	12-24	5.9	1.03	0.600	0.189	0.015	13
10	0-12	6.1	2.88	2.000	0.354	0.033	13
	12-24	5.9	1.22	0.600	0.157	0.015	14
11	0-12	6.1	2.94	1.824	0.288	0.033	14
	12-24	5.9	1.01	0.600	0.157	0.015	10
12	0-12	6.0	3.05	2.000	0.288	0.031	10
	12-24	6.0	1.15	0.600	0.157	0.015	10

*Acid (pH 4.8) ammonium acetate extractable.

Table 32 --(continued)

Lysi-meter No.	Soil (inches)	pH	Exchange capacity (me./100 g.)	Exchangeable bases (me./100 g.)			Extractable* phosphorus (lbs./A)
				Ca	Mg	K	P_2O_5
			Second sampling (4-15-59)				
1	0-12	5.8	2.02	1.200	0.436	0.020	28
	12-24	5.8	1.01	0.476	0.132	0.031	13
2	0-12	5.8	2.33	1.376	0.230	0.066	22
	12-24	6.0	1.51	0.600	0.107	0.084	17
3	0-12	5.6	2.32	1.550	0.189	0.031	26
	12-24	5.9	1.72	0.550	0.107	0.031	14
4	0-12	5.4	2.33	1.200	0.189	0.043	48
	12-24	5.8	1.62	0.550	0.107	0.066	23
5	0-12	5.4	2.15	1.200	0.189	0.031	31
	12-24	5.8	1.44	0.476	0.107	0.043	11
6	0-12	5.8	3.22	2.000	0.230	0.084	35
	12-24	5.9	1.11	0.476	0.189	0.054	15
7	0-12	5.7	2.15	2.050	0.230	0.020	28
	12-24	6.0	1.52	0.550	0.132	0.015	18
8	0-12	5.7	3.05	1.626	0.263	0.031	29
	12-24	5.7	1.03	0.476	0.132	0.015	17
9	0-12	5.5	2.42	1.550	0.157	0.033	28
	12-24	5.6	1.21	0.476	0.132	0.031	15
10	0-12	5.7	2.53	1.400	0.288	0.042	24
	12-24	5.7	1.32	0.500	0.189	0.015	15
11	0-12	5.7	2.44	1.500	0.354	0.033	13
	12-24	5.7	1.33	0.476	0.132	0.023	13
12	0-12	5.4	1.97	1.150	0.288	0.046	26
	12-24	5.8	1.22	0.400	0.132	0.079	13

*Acid (pH 4.8) ammonium acetate extractable.

Table 32--(continued)

Lysimeter No.	Soil (inches)	pH	Exchange capacity (me./100 g.)	Exchangeable bases (me./100 g.) Ca	Mg	K	Extractable* phosphorus (lbs./A) P_2O_5
			Third sampling (9-9-59)				
1	0-12	6.0	1.94	2.800	0.230	0.043	20
	12-24	5.8	1.31	0.926	0.132	0.033	10
2	0-12	5.9	2.15	2.450	0.157	0.066	30
	12-24	5.9	1.60	0.750	0.107	0.087	21
3	0-12	6.2	2.42	3.000	0.230	0.046	52
	12-24	6.0	1.40	0.750	0.107	0.059	10
4	0-12	6.0	2.07	1.824	0.157	0.031	65
	12-24	5.9	1.05	0.600	0.107	0.046	11
5	0-12	6.0	2.52	1.600	0.132	0.031	70
	12-24	6.0	1.32	0.600	0.132	0.031	16
6	0-12	6.0	2.84	1.824	0.189	0.043	30
	12-24	6.1	1.04	0.476	0.107	0.054	12
7	0-12	5.9	2.34	1.626	0.157	0.031	36
	12-24	6.0	1.31	0.476	0.107	0.015	15
8	0-12	6.1	2.46	1.626	0.107	0.031	49
	12-24	5.8	1.12	0.476	0.107	0.015	12
9	0-12	5.7	2.07	1.200	0.107	0.031	65
	12-24	5.7	1.04	0.476	0.107	0.020	15
10	0-12	6.2	2.26	1.450	0.157	0.031	35
	12-24	6.0	1.03	0.550	0.082	0.015	11
11	0-12	6.2	2.18	1.626	0.189	0.043	30
	12-24	5.8	1.03	0.476	0.082	0.015	10
12	0-12	6.3	2.06	1.550	0.132	0.043	48
	12-24	5.8	1.12	0.476	0.082	0.046	11

*Acid (pH 4.8) ammonium acetate extractable.

Table 33--The pH of leachings collected from a 4-foot profile of Arredondo fine sand in large lysimeters.

Leachings	Lysimeters											
Number	1	2	3	4	5	6	7	8	9	10	11	12
					Winter crops							
1	7.1	7.0	5.6	7.3	7.6	7.7	7.8	7.8	7.8	7.8	7.8	7.8
2	5.6	7.0	7.4	7.5	7.6	7.7	7.8	7.8	7.8	7.8	7.8	7.7
3	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.8	7.8	7.8	7.7
4	7.8	7.8	7.8	7.6	7.7	7.5	7.6	7.5	7.5	7.6	7.5	7.5
5	7.5	7.5	7.4	7.4	7.5	7.5	7.5	7.5	5.8	7.0	7.0	7.1
6	6.8	7.0	7.2	7.2	7.4	7.4	7.6	7.4	7.4	7.4	7.3	7.3
7	7.0	6.9	7.1	7.2	7.3	7.5	7.6	7.6	7.6	7.7	7.6	7.4
8	5.8	7.1	7.4	7.4	7.5	7.5	7.8	8.0	7.8	8.0	7.9	7.7
9	6.9	7.1	7.3	7.3	7.3	---	7.7	---	7.5	---	7.4	7.4
10	7.4	7.5	7.3	7.2	7.2	---	7.1	---	7.8	---	7.5	7.5
11	7.6	7.3	7.4	7.5	7.6	---	7.5	---	7.8	---	7.5	7.5
12	7.5	7.3	7.5	7.3	7.3	---	7.3	7.7	8.0	---	6.5	7.7
13	7.4	7.6	7.5	7.5	7.7	8.0	7.9	7.9	7.5	8.1	7.6	7.6
14	7.6	7.4	7.4	7.3	7.2	7.9	7.9	7.9	7.5	8.0	7.8	7.7
15	7.7	7.3	7.4	7.3	7.4	8.0	8.0	8.0	7.6	8.1	7.8	7.6
16	7.8	6.6	7.2	7.2	7.4	7.9	7.9	8.0	7.5	8.0	7.8	7.5
17	7.4	7.5	7.5	7.5	7.5	7.8	7.9	8.0	7.6	7.9	7.8	7.5
18	7.1	6.7	6.1	6.6	5.6	---	5.7	---	5.8	---	6.8	6.2
19	---	---	---	6.7	6.3	---	---	---	6.7	---	---	---
20	6.9	6.7	6.6	7.2	7.6	---	6.0	8.0	7.7	---	7.4	6.8

Table 33 --(continued)

Leachings	Lysimeters											
Number	1	2	3	4	5	6	7	8	9	10	11	12
						Summer crops						
21	6.0	6.9	7.2	7.1	7.1	7.8	7.4	7.0	7.3	7.2	7.5	7.2
22	7.3	7.3	7.5	7.2	7.4	7.6	7.7	7.6	7.1	7.6	7.5	7.3
23	7.4	7.2	7.3	7.3	7.3	6.0	7.0	7.4	7.4	7.6	7.5	7.2
24	6.6	5.2	5.4	7.0	7.3	7.5	7.5	7.5	7.4	7.5	7.4	5.3
25	4.9	5.0	5.5	6.5	6.3	7.2	5.7	6.1	5.9	7.0	5.1	6.4
26	6.1	5.3	6.7	6.1	7.0	7.2	7.2	7.4	5.5	5.8	6.6	6.8
27	6.8	4.8	6.8	5.4	7.0	7.5	7.0	6.9	6.9	7.3	5.5	6.8
28	6.9	6.9	7.2	7.3	7.4	---	7.6	---	7.5	---	7.6	7.3
29	7.4	7.3	7.4	7.4	7.5	---	7.6	---	7.6	---	7.5	7.4
30	7.4	7.3	7.5	7.4	7.5	7.8	7.8	7.8	7.7	7.9	7.8	7.6
31	---	---	---	6.8	7.1	---	---	---	7.4	---	---	---
32	---	---	---	7.1	7.3	---	7.3	---	7.5	---	7.4	---
33	7.3	---	7.3	7.2	7.4	---	7.7	---	7.3	---	---	---
34	---	7.6	---	---	---	---	---	---	---	---	7.2	7.2
35	7.8	---	7.6	7.3	7.4	8.1	7.7	7.8	7.4	7.9	---	---
36	---	---	---	7.2	7.3	---	---	---	7.5	---	---	---
37	---	7.0	---	6.8	7.0	8.0	8.0	7.8	7.4	7.9	7.9	7.4
38	7.2	6.9	7.0	6.9	7.2	7.9	7.7	7.7	7.4	7.5	7.7	7.2
39	7.2	6.7	7.1	7.0	7.3	6.9	7.7	7.6	7.4	7.5	7.7	7.2

Table 34--Total bi-weekly rainfall recorded at the lysimeter area from November 1, 1958 to September 30, 1959.

Date	Inches of rain
November 1-14	3.25
November 15-30	0.03
December 1-14	2.17
December 15-31	0.98
January 1-14	2.78
January 15-31	1.09
February 1-14	2.49
February 15-28	1.87
March 1-14	3.06
March 15-31	7.73
April 1-14	2.45
April 15-30	4.41
May 1-14	1.35
May 15-31	7.79
June 1-14	1.53
June 15-30	3.90
July 1-14	1.92
July 15-31	1.13
August 1-14	5.82
August 15-31	1.93
September 1-14	3.68
September 15-30	1.86
Total	62.22

Table 35--Milliequivalents of ions leached through Lakeland fine sand cropped to millet fertilized with seven potassium sources at the rate of 200 pounds of K_2O per acre.

Leachings		Milliequivalents of ions in leachates					
		K	Ca	Mg	NO_3-N	Cl	SO_4-S
Number	ml.						
			Soil (check)				
1	3,583	0.49	17.53	1.60	2.76	1.64	1.88
2	4,323	0.12	0.50	0.16	Tr.	0.98	0.71
3	5,210	0.19	9.46	1.03	10.02	Tr.	1.13
Total	13,116	0.80	27.49	2.79	12.78	2.62	3.73
			K_2CO_3				
1	3,173	0.65	15.24	1.38	1.51	2.42	2.03
2	4,620	0.22	0.50	0.25	Tr.	1.03	0.88
3	4,920	0.41	2.94	0.54	4.74	Tr.	0.54
Total	12,713	1.28	18.68	2.17	6.25	3.45	3.45
			KPO_3*				
1	3,443	0.71	10.84	1.38	2.92	2.48	0.87
2	4,527	0.28	0.39	0.11	Tr.	1.02	0.51
3	4,873	0.33	2.22	0.43	5.26	Tr.	0.26
Total	12,843	1.32	13.45	1.92	8.18	3.50	1.64
			KPO_3				
1	3,693	0.83	13.13	0.97	2.55	2.72	1.96
2	4,293	0.23	0.41	0.16	Tr.	0.97	0.44
3	4,903	0.32	1.94	0.39	4.64	Tr.	0.39
Total	12,889	1.38	15.48	1.52	7.19	3.69	2.79
			KH_2PO_4				
1	3,623	0.88	10.61	0.96	2.36	1.68	1.16
2	4,363	0.34	0.40	0.14	Tr.	1.01	1.05
3	4,847	0.33	1.63	0.45	4.22	Tr.	0.43
Total	12,833	1.55	12.64	1.55	6.58	2.69	2.64

*Slowly H_2O soluble, other sources completely H_2O soluble.

Table 35--(continued)

Leachings Number	ml.	K	Ca	Mg	NO_3-N	Cl	SO_4-S
			K_2SO_4				
1	3,550	1.86	32.05	2.57	0.99	1.66	14.81
2	4,227	0.24	0.93	0.32	Tr.	0.96	8.86
3	4,850	0.42	1.78	0.24	4.00	Tr.	2.01
Total	12,627	2.52	34.76	3.13	4.99	2.62	25.68
			KCl				
1	3,613	2.24	34.36	2.08	2.36	28.69	1.88
2	4,503	0.25	0.46	0.12	Tr.	0.98	1.08
3	4,887	0.24	1.70	0.24	4.02	Tr.	0.36
Total	13,003	2.86	36.52	2.44	6.38	29.67	2.24
			KNO_3				
1	3,807	3.27	30.56	2.54	11.81	1.73	2.03
2	4,393	0.40	0.39	0.14	Tr.	0.99	0.48
3	4,807	0.39	1.86	0.29	5.27	Tr.	0.40
Total	13,007	4.06	32.81	2.97	17.08	2.72	2.91

Milliequivalents of ions in leachates (columns K through SO_4-S).

Table 36 --Milliequivalents of ions leached through Arredondo fine sand cropped to millet fertilized with three potassium sources of varying water solubility and particle size.

Leachings		Milliequivalents of ions in leachates				
		K	Ca	Mg	NO_3-N	Cl
Number	ml.					
		Soil (check)				
1	2,995	0.30	2.54	2.36	6.30	1.33
2	9,905	0.21	1.63	1.28	3.82	Tr.
3	5,050	0.25	3.07	0.50	4.08	Tr.
Total	17,950	0.76	7.24	4.14	14.20	1.33
		KCl--35 mesh size (100% W.S.)				
1	2,975	2.84	8.37	7.27	6.74	24.23
2	10,390	0.30	1.23	1.12	0.92	Tr.
3	5,010	0.61	1.52	0.41	2.31	Tr.
Total	18,375	3.75	11.12	8.80	9.97	24.23
		KCl--6 + 14 mesh size (100% W.S.)				
1	2,940	2.62	7.84	6.65	6.74	19.95
2	9,935	0.25	0.70	0.48	1.04	Tr.
3	5,060	0.83	0.86	0.08	1.32	Tr.
Total	17,935	3.70	9.40	7.21	9.10	19.95
		KCl--3/8 + 4 mesh size (100% W.S.)				
1	3.340	5.96	7.99	6.53	6.80	26.15
2	9,865	0.35	1.27	1.03	2.32	Tr.
3	4,965	0.97	0.85	0.08	1.28	Tr.
Total	18,170	7.28	10.11	7.64	10.40	26.15
		KPO_3--35 mesh size (13.7% W.S.)				
1	2,925	0.52	4.32	2.40	4.51	1.32
2	9,800	0.77	0.84	0.91	2.31	Tr.
3	4,990	0.61	0.97	0.21	1.33	Tr.
Total	17,715	1.90	6.13	3.52	8.15	1.32

Table 36--(continued)

Leachings		Milliequivalents of ions in leachates				
Number	ml.	K	Ca	Mg	NO_3-N	Cl
KPO_3--6 + 14 mesh size (9.0% W.S.)						
1	2,970	0.62	4.22	4.79	7.56	3.79
2	10,240	0.57	1.11	1.08	1.93	Tr.
3	5,050	0.81	1.12	0.07	1.56	Tr.
Total	18,260	2.00	6.45	5.94	11.05	3.79
KPO_3--3/8 + 4 mesh size (13.0% W.S.)						
1	2,790	0.34	4.26	3.31	4.68	2.00
2	10,160	0.25	1.02	0.94	1.79	Tr.
3	4,960	0.76	1.40	0.18	2.34	Tr.
Total	17,910	1.35	6.68	4.43	8.81	2.00
$K_2CaP_2O_7$--35 mesh size (7.2% W.S.)						
1	2,970	0.61	3.68	3.15	5.74	4.59
2	10,340	0.31	1.64	0.60	1.45	Tr.
3	5,070	0.50	1.55	0.50	2.61	Tr.
Total	18,380	1.42	6.87	4.25	9.80	4.59
$K_2CaP_2O_7$--6 + 14 mesh size (7.2% W.S.)						
1	2,940	0.56	4.31	4.34	7.24	6.55
2	9,635	0.18	1.04	0.81	2.06	Tr.
3	3,540	0.50	1.26	0.08	2.14	Tr.
Total	17,615	1.24	6.61	5.23	11.44	6.55
$K_2CaP_2O_7$--3/8 + 4 mesh size (7.5% W.S.)						
1	2,180	0.20	2.66	1.70	4.25	1.97
2	9,990	0.27	1.11	1.08	2.87	Tr.
3	5,070	0.73	1.12	0.27	2.03	Tr.
Total	17,240	1.20	4.89	3.05	9.15	1.97

Table 37--The analysis of variance of the oven-dry weight of millet, milligrams of potassium absorbed, and milligrams of potassium leached from Greenhouse Experiment No. 1.

Source of variation	Degrees of freedom	Mean squares for cuttings		
		1st	2nd	Total
Yields				
Treatments	7	7.8**	121.8**	91.7**
Check vs. K sources	1	4.8**	740.9**	583.3**
K sources	6	3.0	18.6	9.8
Error	16	0.6	11.0	3.9
Total	23			
Potassium absorption				
Treatments	7	62,994.3**	20,773.6**	73,388.8**
Check vs. K sources	1	380,619.1**	90,275.9**	427,921.7**
K sources	6	10,056.8**	9,189.9**	14,299.9**
Error	16	1,019.5	1,462.6	513.4
Total	23			

Potassium leached	Degrees of freedom	Mean squares for leachings			
		1st	2nd	3rd	Total
Treatments	7	4,487.5**	32.6**	782.9**	2,729.5**
Check vs. K sources	1	3,996.5**	109.0**	4,143.2**	3,175.1**
K sources	6	4,569.5**	19.9*	222.8*	3,131.5**
Error	16	121.5	5.8	78.6	56.9
Total	23				

*Significant at 0.05 level.
**Significant at 0.01 level.

Table 38--The analysis of variance of the oven-dry weight of millet, percent potassium content, milligrams of potassium absorbed, and milligrams of potassium leached from Greenhouse Experiment No. 2.

Source of variation	Degrees of freedom	Mean squares for cuttings			Total
		1st	2nd	3rd	
Yields					
Treatments	11	14.8	2.3	6.6**	41.1**
Check (soil)	1	3.9	17.4	51.4**	126.5**
K - sources	10	10.0	0.8	2.1	2.9
Error	12	5.4	1.2	2.3	2.8
Total	23				
Potassium content					
Treatments	11	4.83**	0.32*	0.23	
Check (soil)	1	5.37**	2.20**	---	
K - sources	10	4.60**	0.13	---	
Error	12	0.11	0.10	0.26	
Total	23				
Potassium absorption					
Treatments	11	22.6**	19.6**	5.7	12.0**
Check (soil)	1	160.0**	13.9**	3.4	97.8**
K - sources	10	8.9	5.7	2.3	3.4**
Error	12	3.6	2.6	4.1	1.1
Total	23				
Potassium leached					
Treatments	11	8778.6**	88.4**	113.9*	3376.6**
Check (soil)	1	3951.7**	50.6	575.8**	2943.7**
K - sources	10	9261.3**	92.2**	67.7	3479.9**
Error	12	258.9	13.5	40.3	101.8
Total	23				

*Significant at 0.05 level.
**Significant at 0.01 level.

Table 39--The analysis of variance of the milligrams of potassium leached from Greenhouse Experiment No. 3.

Source of variation	Degrees of freedom	Mean squares for potassium leached
Treatments	5	
Crops	2	55,975.2
Leaching rates	1	6,666.7
Crops x leaching rates	2	5,077.7 **
Error	18	155.0
Total	23	

** Significant at the 0.01 level.

Table 40--The analysis of variance for the milligrams of potassium leached from Lakeland and Red Bay soils from Laboratory Experiment No. 1.

Source of variations	Degrees of freedom	Mean squares for K - leached	
		Lakeland soil	Red Bay soil
Treatments	15	49.77	4.52
K - materials	3	229.72	8.17
Leaching dates	3	9.82	12.52
Interaction	9	3.10**	0.53**
Error	32	0.16	0.04
Total	47		

**Significant at 0.01 level.

Table 41--The analysis of variance for the milligrams of potassium leached from Lakeland and Red Bay soils from Laboratory Experiment No. 2.

Source of variations	Degrees of freedom	Mean squares for K - leached	
		Lakeland soil	Red Bay soil
Treatments	3	89.8**	12.5**
Error	8	0.8	0.2
Total	11		

**Significant at 0.01 level.

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BIOGRAPHY

Clifford Newell Nolan was born in Franklin County, Florida, on October 22, 1925. He is the son of Mrs. N. C. Nolan and the late Mr. N. C. Nolan of Live Oak, Florida.

He received his elementary education at Central Grammar School, and was graduated from Suwannee High School, Live Oak, Florida, in April, 1944. He entered the University of Florida in September, 1948, and was graduated in August, 1951, with a degree of Bachelor of Science in Agriculture with a major in Soil Fertility.

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He served in the United States Marine Corps from December, 1943, to May, 1946. From September, 1951, to September, 1957, he was employed by the Georgia Agricultural Experiment Station, University of Georgia, as Soil Technician. Since September, 1957, he has been employed as one-third time Research Assistant for the Soils Department, Florida Agricultural Experiment Station, University of Florida.

This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of the committee. It was submitted to the Dean of the College of Agriculture and to the Graduate Council and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

June 6, 1960

Dean, College of Agriculture

Dean, Graduate School

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